Analysing Residential Water Demand in Portuguese Municipalities and Its Implications in Policymaking

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Abstract: - This article aims to analyze residential water demand in Portuguese municipalities and its political implications. Understanding residential water demand is crucial to ensure environmental sustainability and community well-being in the context of natural resource scarcity and climate change. This study quantifies and characterizes water demand in several Portuguese municipalities, identifying patterns and trends. It also examines the main determinants of residential water demand, including demographic, socio-economic, and environmental factors. In addition, the effectiveness of current policies and measures to promote efficient water consumption is assessed. The findings highlight the need for comprehensive and up-to-date analysis to inform effective national water policies. The conclusions allow practical recommendations for improving water demand management and promoting sustainability in Portugal.

Key-Words: - Water demand, municipalities, policymaking, economics of water, sustainability, residential water use, urban water management, water scarcity.

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1 Introduction

The efficient management of water resources is a growing concern around the world. With the scarcity of natural resources and the challenges posed by climate change, understanding residential water demand becomes crucial to ensure environmental sustainability and the well-being of communities. The availability of drinking water is essential for human life and for the functioning of various socio-economic sectors, including agriculture, industry, and tourism. However, the water supply is under great pressure due to population growth, urbanization and changing consumption habits, which raises questions about how best to manage it sustainably. Through initiatives such as educational campaigns and reducing waste in the system, the European Union is working to encourage the prudent use of water. However, there is no recent data on what influence these technologies exert on water management in European countries. Considering that the nation of Portugal already shows signs of water scarcity in most parts, deciphering the driving factors that affect domestic water consumption is the main way to develop effective strategies and plans for water management. The objective of this paper is to fill this hiatus with an updated version of the water demand analysis for the cities of Portugal and its impact on the national policies related to water. It prompts two questions: What are the laws that can be enacted to facilitate a more efficient manner regarding water conservation? What is the demographic factor affecting domestic water consumption in Portuguese cities? Our study, therefore, tried to establish what specific demographic trends were driving the demand for water in all municipalities and took into consideration the relationship between demographic trends and water consumption. In relation to the above, the second part of our research focuses on the translation of this knowledge into actionable policies. This will not only go a long way in entrenching the demographic basis of water consumption but also give credence to the potential for targeted and effective conservation strategies.

Matching demographic knowledge with policy intervention, this research tries to proffer workable advice that municipalities may adopt in an effort toward the sustainability of water resources.

This document is structured as follows. The next section presents an overview of the literature related to residential water demand and its management. Subsequently, we present the methodology used to collect and analyse the data, followed by the results obtained and their discussion aiming at answering the research objectives. Finally, conclusions and recommendations for future policies and practices are presented.

1.1 Literature Review

Recently, it has become clear that the strategy of expanding water supply to meet growing demand is limited by the scarcity of available water resources. Consequently, there has been a change of direction in water management, with the perception that continuous expansion of supply is not enough. In this context, policies aimed at managing demand have sparked significant debates between water service managers, policymakers, and economists. Aspects specific to the water sector, such as the obligation to provide water to all, together with the growing interest in promoting the efficient use of water by consumers, require a proper assessment of the expected effects of pricing policies on water consumption. Thus, estimating domestic water demand is a fundamental requirement for any water policy initiative, given the relevance of domestic consumption in the urban context. Many contributions to analyzing these effects come from case studies that seek to estimate water demand functions, basing their conclusions on theoretical and empirical studies.

To formulate policies aimed at managing water demand, it is essential to understand how water is consumed in urban areas. However, domestic water consumption may be highly influenced by various factors, with local particularities playing a significant role. To achieve sustainable water demand management, defined as the development and practical implementation of strategies to influence demand [1] it is imperative to have a detailed understanding of household water use patterns. An exploratory study by [2] investigated the influence of socio-demographic characteristics on household water end-uses. Using an approach based on collecting data on household attributes, water consumption patterns, and conservation behaviors, the study highlighted the importance of factors such as household size, the presence of children/elderly people, and income/education levels in adapting domestic water use.

In their study, [3] analyzed the determining factors associated with residential water consumption in the city of Aveiro, Portugal, based on data collected through a questionnaire. The results showed that households with more intensive use of the shower and greater consumption of meals at home had higher levels of water consumption. Other studies, such as that by [1] assessed the impact of family composition on water consumption and concluded that there is a general decrease in per capita consumption as family size increases, suggesting better economies of scale with a larger number of people in the household.

Although the application of water-efficient technologies, products, and behaviours can lead to a significant decrease in water consumption, the residential sector remains the largest consumer of water in urban areas, compared to the commercial and industrial sectors, [4]. As such, a reduction in domestic water consumption may bring important benefits, including the postponement of investments in expanding the water supply system and modernizing pumping infrastructure. Studies such as those carried out by [1], [5] and [6] have investigated the impact of efficiency measures on domestic water consumption. Water use efficiency therefore has to consider user behaviour and technical efficiency.

Ensuring the long-term sustainability of this resource involves conducting research on residential water use patterns that inform a water management strategy.

Recently, it has become a topical issue due to concern for the environment and, hence, the availability of water resources. Given that background, the analysis of the pattern of water use in Portugal is critical in determining what is being driven and the implication for policy. In this manner, understanding the driving factors behind patterns of water consumption could help gather data that might be useful in reducing water pressure and assisting conservation efforts.

Unlike other research works, this study looks at how the completion of the knowledge gaps about factors driving water usage in towns can further enhance our understanding of water demand. It takes into consideration factors such as home income and family size, with respect to the local climate, to solve issues about water usage. In addition, it claims to inform and enhance water management policies through policy recommendations tailored according to specific environmental and population characteristics of

Portugal, which also distinguishes this research from most studies that might not even consider such differences or policy implications.

1.2 Methodology

In Portugal, the control and proper management of the demand for water necessitate the need to have a perfect understanding of residential water consumption trends in a greater framework of the water economy. For this purpose, the research study examines the complex facets of residential water demand and their driving factors so as to lay the foundations for successful policy interventions that favor sustainable habits of water use. Our analytical methodology underpins quantitative research combined with qualitative insight, adopting a multi-faceted approach to the complex interaction of socio-economic, demographic, and political factors that influence the nature of water use. Data are sourced from municipal water supply companies, national statistical databases, and relevant research studies in order to capture the complex nature of residential water demand. These data sources provide a rich amount of information on the characteristics of the households, water use parameters, climatic variables, and political dynamics. Our descriptive study will make it crystal clear what the dominant patterns in trends and discrepancies that mark residential water consumption in municipalities all over Portugal. We will conduct a critical comparative study of the political implications of how governance frameworks control the demand for water and how political influences impact consumer behavior. Solutions and strategies will be provided in order to enable the management and conservation of water for residential consumption, considering the access of this resource for all, after its contextualization and analysis.

We can, therefore, tease apart the complexities of water consumptions behaviour using robust data collection methods and analysis techniques to inform evidence-based policy interventions.

2 Understanding Water Economics

2.1 Conceptual Framework of Water Economics

From this perspective, water economics engages in the global system that deals with the production, distribution, and consumption of water resources, integral to the different sectors of the economy. Water management and utilization are focused right from its natural source to its final applications, considering it not just as a physical good but also as a social good. Water is an inseparable factor in discussions related to morality and economic values. It touches nearly every part of social life, making it a very important focus of economics and morals alike, [7]. While being a resource basic to life itself and human functions in agriculture, industry, and personal uses, management and apportionment influence and are influenced by economic pursuits everywhere. This makes water shortage a potential threat to ecological systems and also affects economic growth and stability through its role in irrigation, sanitation, and production. This multi-faceted relationship requires efficient water management policies, ensuring sustainability and facilitating economic activities accordingly, [8].

The same water resources come in fact from Portugal's surface and underground sources. The main rivers, such as the Douro, the Tejo, the Guadiana, the Sado, and the Mondego, are indeed basic, covering about three-quarters of the territory, with a relevant flow from more than 5,000 km2 for each river basin. The country also uses a substantial portion of water resources from lakes, reservoirs, and underground aquifers; these waters are primarily used for public supply due to their good quality, [9]. Water resources are spread out unsteadily over Portugal with major regional disparities regarding the availability of water. Precipitation is generally higher in the north, with northern rivers continuing to have higher flows accordingly. In contrast, the southern regions, such as the Algarve, suffer from a shortage of water. These are exacerbated by the high demand from tourism and by intensive agriculture that over-exploits the limited water resources beyond their natural replenishment rate, [10].

Figure 1 (Appendix) presents important geographical differences in the average annual runoffs for the Portuguese hydrographic regions. RH3-Douro, RH4-Vouga, Mondego, Lis, and RH5-Tejo e Ribeiras do Oeste must be underlined as representative regions that present higher runoff volumes in all the analyzed precipitation situations when compared with other areas. This indicates that there are regional differences either in the river basin characteristics or precipitation patterns, so any water resource management policies must be region-specific to work out these disparities effectively, [11].

The water infrastructure in Portugal consists of an extensive network of large dams and reservoirs, which are basic to the management of the country's water supply. In addition, the infrastructures

developed in the country for water transport and treatment have guaranteed that most of its population has access to drinking water. Over the more recent decades, there were significant improvements to the services of sanitation and water supply, partly funded through the European Union, with contributions to the quality and scope of water services across the country, [12].

In Figure 2 (Appendix) we may see the evolution of the infrastructures of the Multimunicipal Wastewater Sanitation System in Portugal is summarized, covering the period from 2005 to 2015. It shows the total length and number of interceptors, pumping stations, and wastewater treatment plants (WWTPs) existing at the end of 2015. Specifically, there were 447.3 kilometers of interceptors, 175 pumping stations, and 66 wastewater treatment plants. The bar chart illustrates the annual growth of these infrastructures over the decade, showing a steady increase in the number of pumping stations and wastewater treatment plants, while the length of interceptors shows a more varied trajectory, with significant growth, [13].

In addition, [14] indicates that the percentage of households connected to public water supply systems has increased from 80 percent in 1991 to 96 percent in 2021. At the same time, connection to sewage systems increased from 60 percent to 86 percent in the same period. Connection to wastewater treatment plants improved substantially, from 27 percent in 1995 to 84 percent in 2020.

The data presented in Figure 3 (Appendix), not only illustrates the significant growth of new water infrastructures in recent decades but also highlights the complex interaction between the natural availability of water and human factors. Infrastructure development and management practices are proving crucial to meeting the challenges of water distribution and scarcity in Portugal, highlighting the importance of an integrated and strategic approach to water resource management.

2.2 Overview of Water Resources Management in Portugal

Water supply is a critical aspect of national infrastructure, with significant economic implications. In Portugal, the management and economics of water supply have been shaped by historical, social, and political factors, influencing pricing strategies, market structures, the provision of public and private services, as well as the challenges posed by financial and environmental pressures.

Water supply infrastructures in Portugal have historically had serious shortcomings, particularly before the democratic era that began in 1974. During this period, a lack of investment and economic stagnation made it difficult to provide basic water supply services to the population, [15]. In fact, water supply coverage increased from 81% to 96% after democratization 017. This was mainly due to advances brought about by public policies and greater funding to modernize the water supply systems. One of the main areas of economic analysis has been the role of prices in the management of urban water supply systems in Portugal. Research underlines that water price is important in a sustainable economy and for the efficient use of water. Three river basins in southern Portugal were analyzed in [16] and the authors have mentioned that there is a need for an efficient pricing system that can control the demand and ensure the financial sustainability of the water supply services. This research noted that pricing can be a way to motivate people toward sustainable utilization of the resource, based on its availability and consumption.

Economic valuation often advances the social aspects of water pricing. More importantly, affordability concerns and scarcity might affect low-income, [17]. The emergence of these challenges creates a demand for legislation that can protect vulnerable groups without impairing the financial sustainability of the water utilities themselves. A very relevant issue from an economic point of view is whether the provision of water service in Portugal is to be left to the public or the private sector. In an empirical comparative study of the performance and efficiency of public-private water service providers, [18] concluded that while private provision may allow the capture of some efficiencies, the public provision is instrumental in guaranteeing access and ensuring that issues are resolved at the level of social equity. This would, therefore, suggest that while private involvement might be the means for introducing competitive efficiencies, services by the public better meet the needs of people who are marginalized.

The water sector in Portugal has also undergone transformations of neoliberal and financial policies. Political reforms and economic pressures favored the trend towards market-based strategies and privatization, [15]. The latter, though, has underlined possible negative implications of strong reliance on the private sector for public essentials and water affordability, in particular, within recessionary economic conditions. Comparisons across nations have also been used to analyze the

efficiency of water companies. In their comparison of water utilities in Portugal and Italy, [19] discussed the impacting factors of the company's ownership, size, diversification, and vertical integration on efficiency. They found that the larger the company with more diversification, the better the results were in terms of service provision and cost efficiency.

Among all basic social services, such as water supply, political funding plays a major role in the development and continuance of such services. Portugal benefits from priority investment programs in water supply as a member of the European Union. To meet the population's water needs, facilities must be maintained and improved, which is ensured by the efficient use of financial resources. The importance of political finance in enhancing the effectiveness and financial viability of water supply systems is demonstrated by strategic plans such as PENSAAR 2020 [20] (Table 1, Appendix). The pricing strategy and the standard of services offered to the population reflect the alignment of this plan with the concepts of effective cost recovery and fair tariffs, modernization and new technologies, waste minimization, and resource optimization.

By emphasizing the sustainable management of water resources and improving water quality, the Portuguese government's PENSAAR 2020 strategy [20], a strategic project covering the period from 2014 to 2020, supports economic methods. The aim of this project is to comply with European directives, including the Drinking Water Directive, the Urban Waste Water Directive, and the Water Framework Directive. The plan provides for the construction and modernization of water supply and wastewater treatment infrastructures, as well as the use of cutting-edge technologies to increase the efficiency of water services, with a total investment of 881 million euros, 420 million of which are financed by the European Investment Bank (EIB), [21].

2.3 The Position of Residential Water Demand within the General View of Water Economics

Understanding the economic aspects of water demand is particularly relevant for the elaboration of an effective water management policy. The pattern of water consumption in Portugal, as elsewhere, depends on various socio-economic factors like development, pricing methodology, climate change, and agricultural use. This section explores the main economic factors determining water demand in Portugal, along with the impact of climate change, legislative initiatives, and domestic, agricultural, and industrial uses.

Socio-demographic and economic factors determine residential water consumption in Portugal. In the view of [22] price structures, income levels, household size, and climatic conditions are the critical determinants of this demand. Generally, a higher cost fosters the conservation of water and lower consumption. The study established that block pricing, where higher consumption translates into higher unit rates, is an efficient system in motivating household economies to save water. It was emphasized in [23] that, to reflect the cost of supply, as well as promote efficient use, there is a need for water tariffs with appropriate cost recovery techniques. The adoption of the Water Framework Directive in Portugal underlined that prices ought to be set by using economic reasoning for demand balancing and utility viability in the long term. Because of irrigation applied in crop production, agriculture represents more than 75% of the total water use in Portugal. Therefore, the optimization of irrigation techniques is of prime importance if economic viability and environmental sustainability are to be pursued in management. This would strongly improve the efficiency of water use and decrease the respective costs, [24]. This has ensured efficiency for long-term sustainability as the technological advances in water management, which include the use of weather stations and probes are expected to lead to a considerable reduction in consumption of energy and fertilizers apart from decreasing water consumption by 20-50%. In this context, economic growth and urbanization serve to increase the demand for water from cities and industries. The future vulnerability of water demand under an integrated modelling approach in the Montargil reservoir basin was studied in [25]. The increasing demand from urban and industrial growth requires, in turn, quick forecasts and planning for water supply management. Employing regression approaches, [25] proposed a socio-demographic, meteorological, and economic data-driven approach for demand scenario planning to predict water demand in network sectors that proves crucial for efficient water management.

It is a fact that climate change seriously affects water demand management in Portugal. After analysing the combined effects of socio-economic factors and climate change on freshwater availability in the southern part of the country, [26] concluded that such changes may heighten water scarcity and necessitate the formation of adaptation measures. Reference [27] stated that "higher

temperatures and changing rainfall quantities may increase the demand for water supply while simultaneously reducing supplies, and steps must be taken well in advance to manage supplies sustainably". Under the current regime of drought in Portugal, reinforcement in the National Water Strategy is the need of the hour for prudent management of water. Industry and agricultural demands must be weighed against supply and the environmental limitations resulting from the scarcity of water. Besides, the situation is made fantastically complex by the strong demand for tourism, especially in areas like the Algarve, placing added stress on an already thin supply of water resources, [10]. The management of water services has changed over time due to these issues, influenced by European Union policies remodelling the institutional frameworks and infrastructures needed to support the sustainable use of water and improve its quality, [28].

3 Patterns and Determinants of Residential Water Demand

The relevance of water for human life makes the analysis of water residential demand extremely relevant

The instability of water resources is increasing, not only in areas that already suffer from water stress but also in new areas, driven by the change in the hydrological pattern caused by climate change, [29]. Therefore, to increase water resilience in urban areas, a thorough understanding of the determinants of domestic water consumption is required. This is essential for designing and implementing effective water demand management policies and obtaining accurate forecasts of water consumption. Long-term water demand tends to be determined by the characteristics of dwellings and households, [30], [31]. The characteristics of dwellings that influence water consumption are mostly physical aspects. The factors that link water consumption and homes are the age of the house, the number of bathrooms and/or bedrooms, the presence of a garden, the size of dwellings and plots of land, and the presence of devices that reduce water consumption. It was found that in Tunisia, domestic water demand increases by 0,53 percent for each additional room, [32]. Moreover, the year the building was constructed is often mentioned as an important factor in water demand, mainly because newer buildings have more efficient water fixtures, [33], [34], [35]. Regarding water-saving devices, research has shown that replacing existing household appliances with water-efficient alternatives, such as dual-flush toilets, faucet aerators, and low-flow showerheads, can reduce water consumption by 9% to 50%, [36], [37]. However, some studies, [38] have concluded the opposite, that is, households that have consumption-reducing devices generate a compensation effect that leads to greater spending (rebound effect). This is due to a relaxed attitude of users, who have the perception that saving mechanisms solve bad water use practices, when in fact they only help. Additionally, there are also socio-economic and demographic factors, such as income, age distribution, and educational levels, which lead to higher water consumption.

There is a consensus in the literature on the positive relationship between family income and household consumption, i.e. wealthier families have higher standards of living, which leads to higher consumption. On the other hand, poorer households are forced to behave more sparingly due to their financial conditions. However, there is opposition when it comes to people with higher incomes and people with a higher level of education, as a greater awareness of water conservation is expected in more educated social strata. Education levels are therefore correlated with income levels, which can lead to greater consumption due to higher standards of living. On the other hand, greater education leads to greater discernment and rationality in residential water consumption. Another demographic factor addressed by the authors, [39], is the household size or rather the number of people living in a house. The greater the number of residents, the greater the expenditure, but the factor of per capita demand can't be neglected. There can be economies of scale, which lead to lower consumption. This economic effect is reflected in the activities shared by all residents, such as cleaning the house, gardening, and cooking. Another element that has been pointed out is the age of family members, which has both a negative and positive effect on water consumption. Some authors, [36], [40], [41], state that older people have less need for water compared to children, due to more energetic behavior and a greater need to bathe.

In contrast, other authors, [1], [22], [42], [43], [44], reveal that older people spend more time at home than other age groups, which leads to greater water consumption at home as an alternative to the workplace or schools.

3.1 Descriptive and Quantitative Analysis of Residential Water Consumption Patterns in Portuguese Municipalities

To understand and quantify residential water consumption patterns in Portuguese municipalities, two relevant articles were analyzed: Understanding residential water demand: insights from a Survey in Domestic Water uses: Characterisation of daily cycles in the north region of Portugal [2] and in a Mediterranean City. Urban Water Journal [3] and

The first work analyses the residential demand for water and the behavior of the inhabitants of Aveiro, through a survey with 53 valid responses, referring to a group of 163 individuals (107 adults and 56 children). This study (Figure 4, Appendix), estimated the average daily consumption of Aveiro residents at 299 liters/day, with the vast majority spending between 90 and 350 liters/day, and with a per capita consumption of 99 liters/day. These figures were obtained by dividing the total amount to be paid on the bill by the number of inhabitants in the house.

The authors concluded that there is a positive relationship between water consumption in a household and the household size, the presence of children, and income. It is also observed that, for the same income group, households with higher levels of education tend to consume less water. However, there is no correlation between household per capita water consumption and the year the building was constructed.

On the other hand, the behavioral variables show that households with greater use of the washing machine and shower, and with a greater number of meals consumed at home. Have a greater amount of water consumed. Results also show that the lowest per capita water consumption level pertains to households having the most potent attitudes toward water conservation. This finding may suggest the importance attached to the water-conserving habit in helping to reduce the quantity of water used in the household.

A second study covers three regions in the North of Portugal: Porto, Vila Real, and Valpaços. The locations were chosen based on capturing a representative sample of a population with different lifestyles and cultural habits. Porto is the second-largest metropolitan area in the country and is the regional capital of northern Portugal, representing a significant urban environment with high levels of education and income. Vila Real also represents a midsized town in the Douro Valley area, characterized by an average kind of standard concerning education and income. Valpaços is a small rural town in the interior north border region, low in educational and income levels, and highly dependent on agriculture. This sampling would also allow for the analysis of water consumption behavior under urban and rural conditions, as well as under different conditions of education and income levels.

We can then conclude from this that the most used household devices are the washbasins and kitchen sinks, followed by flushing toilets, bathtubs, and lastly, washing machines. However, the bathtub is the appliance which uses the most water per use, followed by the washing machine, the kitchen sink, the dishwasher, and lastly, the washbasin. In terms of daily volume, the kitchen sink is the appliance that uses more water, followed by the bathtub and the flush toilet. The washbasin accounts for 12 percent of the volume used in a day per person, and lastly the washing machine and dishwasher with 8 and 2 percent respectively of the volume used in a day per person. It was also observed that hand washing is the most frequent use during the day, followed by brushing teeth, washing the face, and, finally, shaving. The first three uses consume the most water per use. Shaving is the end use that consumes more with this device. These figures highlight the distribution of water consumption throughout the day and the significant differences in the volumes spent per person in relation to each device.

Finally, these conclusions highlight the importance of considering not only consumption patterns but also demographic and behavioral factors when developing water conservation strategies, [2].

4 Analysing Residential Water Demand

4.1 Methodological Approach

The application of a multivariate coefficient demand model, which can integrate different effects or factors, is very common in the literature. Some examples of multivariate and econometric water demand models are proposed by [45], [46] and [47].

The pooled model was applied due to the limitation of serial data. This model allows data from different units (municipalities) and different periods to be combined, facilitating econometric analysis even with limited data. The choice of this model was validated using the Hausman test and the Breush-Pagan LM test. The Hausman test is used to decide between fixed and random effects models, while the Breush-Pagan LM test helps to decide

between the pooled model and the random effects model, [48], [49]. As in the Hausman test the p-value is greater than 5%, we cannot reject the null hypothesis, so the random effects model is more appropriate. In the LM Breush-Pagan test, however, as the p-value is greater than 5%, we conclude that the pooled model is more appropriate than the random effects model.

The analysis covers a period of 12 years, from 2008 to 2019. This period makes it possible to capture significant variations in both the dependent and independent variables, enabling a robust analysis of the dynamics of water demand over time.

The municipalities included in the study are Aveiro, Coimbra, Braga, Porto, and Gaia. These municipalities were selected due to the availability of consistent data and because they represent a diverse sample concerning socio-demographic and climatic characteristics, even though they are all urban environments close to the coast.

The variables selected for this study are essential to understanding the factors that influence residential water consumption in each municipality. The dependent variable is residential water consumption in each municipality (Qit), using average water consumption in cubic meters per inhabitant in municipality i in year t as a proxy. These variables measure the amount of water consumed by the resident population in each municipality over time.

The independent variables include sociodemographic and climatic factors. Among the socio-demographic variables, we have:

- household income (Incomeit), represented by the average monthly income of workers in municipality i in year t, which captures the financial capacity of households and can influence water consumption.
- the percentage of elderly people (Elderlyit) in municipality i in year t, which verifies whether the presence of a greater number of elderly people in the household affects water demand.
- the average household size (Numresit), which refers to the average number of residents per household, in municipality i in year t, a variable that can directly affect water consumption, since larger households tend to consume more.
- population density (DenPopit), measured by the number of inhabitants per square kilometer in municipality i in year t, aims to assess the existence of spaces such as gardens and backyards. In more populated cities, where there is less space for these environments, it is expected that a higher population density will lead to lower water consumption.

The independent climatic variables are:

- the average annual temperature in municipality i in year t in ºC, (Tempit), as higher temperatures can increase water demand.
- the annual amount of rainfall in mm (Precit in municipality i in year t, as it can influence water consumption, especially in terms of irrigation needs and other water-dependent activities.

So, the econometric model using the previously defined variables and uit as the error term can be formulated as follows:

Qit = β0 + β1 Incomeit + β2 Elderlyit + β3 Numresit + β4 DenPopit + β5 Tempit + β6 Precit + uit

Stata software version 18.5 was used to estimate the model.

4.2 Discussion of Results

As shown in Table 2 (Appendix), from all the variables analyzed, only the percentage of elderly people (β2) and the average family size (β3) were statistically significant at the 5% level, both with a positive coefficient. The same conclusions were reached by [41] and [50] for elderly people. They concluded that as people get older, they use more water. Water use may increase with age because retired people spend more time at home and gardening [51] because children use less water for washing and hygiene than adults, or because health reasons may force older people to use the bathroom more frequently.

Concerning family size, in principle, the higher the number of people living in a household, the larger the aggregate demand is supposed to be. Nonetheless, economies of scale regarding the optimization of water use could not be generally achieved in small households, [52]. Additionally, it is argued in [53] that there is an optimum household size and that beyond this threshold, economies of scale tend to vanish. A negative sign for family size was found by [50], as per capita water consumption decreases when the number of household members increases, since several water uses such as washing, gardening, or even cooking increase less than proportional to the increase in household size. So, literature is not in agreement about the sign of this coefficient, although in our model the influence is positive, that can be a sign that Portuguese

households have not reached these economies of scale.

Although not significant, the variable income (β1) had a positive sign in our model, as widely accepted and empirically demonstrated by the literature, that domestic water consumption is positively correlated with income, [53], [54], [55], [56].

Population density (β4) was also not significant but with a negative sign, as also concluded in [50]. EEA, [57], [58], shows that low density housing is gaining terrain in countries such as France, Portugal or Spain, and it is expected an increase in outdoor uses in these countries and therefore of water consumption as well.

Average annual temperature (β5) was also not significant, but with a positive sign, as also confirmed in [53], illustrating that people spend more time (and use water) at pools and beaches.

Finally, annual rainfall (β6) was not statistically significant but had a negative sign, as also confirmed in [50], since higher rainfall lowers the water demand for gardening (and fills up water cisterns), and higher rainfall reduces water demand from utilities.

The model's R^2 was 0.5627, indicating that approximately 56.27 percent of the variation in residential water consumption is explained by the independent variables included in the model. The adjusted R^2, which is more relevant because it considers the number of variables in the model, was 0.5132. These values suggest that the model has a moderate explanatory power. The F value (11.37) and the associated probability (p<0.0000) indicate that the model is globally significant.

The results indicate that the percentage of elderly people and the average household size have a positive and significant impact on residential water consumption, as expected, and already observed in the literature.

Some weaknesses of the model include:

- Income not adequate: the income coefficient ($\beta 1$) did not prove significant, which may indicate that the average monthly earnings of employees are not the best proxy for household income in the context of residential water demand.
- Population Density Interpretation: The population density coefficient ($\beta 4$) showed a negative sign, as expected, but was not statistically significant, suggesting that the population density measure used may not correctly capture the availability of green space and its impact on water consumption.
- Climate data: The temperature($\beta 5$) and precipitation ($\beta 6$) coefficients were not significant. This may be because climate data is taken for each district, and not specifically for each municipality, which can introduce inaccuracies.
- Water price variable: the non-inclusion of a water price variable (due to the complexity of obtaining and formulating the data).

Therefore, while the model provides some valuable insights, improvements could be made to the choice of variables and the specification of the model to increase its accuracy and explanatory power. One way to make these improvements would be to have access to a better database that could better reflect the selected variables.

5 Water Consumption Due to Pricing Policies

Numerous studies have examined the impact of water pricing regulations on residential water demand in Portugal, especially from the perspective of price elasticity of demand. This idea in economics quantifies how responsive the amount required is to price fluctuations. Water demand generally has been regarded as inelastic, in that price changes induce very slight changes in the levels of consumption. The level of elasticity does depend on a number of factors, including income levels, availability of substitute sources of water, and initial cost of water. In general, [59] demonstrated that elasticity may vary substantially across diverse areas and socioeconomic circumstances, which can significantly impact the efficiency of pricing schemes. Their work derived the implication that effective execution of water price plans is determined by a sophisticated strategy adapted to particular local conditions.

Some of the smart pricing methods put in place within Portugal to control domestic water consumption include an Increasing Block Tariff scheme, where, with an increase in the number of units consumed, the price of water increases per unit. The concept here is that if a higher consumption rate is charged, this would somehow discourage over-consumption and at the same time ensure that basic water needs are met at a relatively cheap price. Studies at ERSAR [60] confirm the incentive role that IBTs have been playing regarding water conservation, with municipalities that have adopted this system showing drops in use among higher-tier consumers.

Another tactical approach that is also used in Portugal is seasonal pricing. It refers to a change in the cost of water based on seasonal demand fluctuations. This works effectively, particularly in summer when water consumption is usually high. For instance, towns in the Algarve have already tested seasonal pricing schemes that react to higher demand and resulted in a 15% decrease in water consumption in peak months. This result indicates how targeted approaches can lead to wide-scale conservation impacts and shows that pricing regulation adjustment with seasonal demand fluctuations is especially effective, [61].

These pricing methods have definable advantages, but their adoptive practices are not without their problems. In fact, for effective enforcement of dynamic price mechanisms, administrative cost and mass public acceptance are essential. The traditional fixed pricing systems that apply a single price independent of the amount of water delivered to the consumers are now, one after another, being replaced with more flexible and responsive pricing mechanisms. These approaches have been shown to be less successful in promoting conservation. Over the course of five years, Lisbon's home water consumption has remarkably decreased by 20% as a result of the implementation of the IBT system and extensive public awareness efforts. Besides effectively reducing water consumption, these measures have encouraged the installation of water-saving appliances such as efficient irrigation systems and low-flow fittings. This Lisbon feat remains a strong demonstration that through efficient policy and public participation, major leaps in water conservation can be achieved with ease, [62].

Furthermore, [62] provided insight into Lisbon's use of green infrastructure, including expanded green spaces and permeable pavements, which enhance the city's ability to naturally manage rainwater and support pricing methods. Since 2008, Lisbon's green spaces have grown by 13%, and 80% of the population lives within 300 meters of these renovated areas. By reducing the urban heat island effect, these NbS (Nature-Based Solutions) increase urban resilience to climate impacts in general. These green solutions actually serve the purposes of the IBT system in peak load control and relieve the burden of the traditional water infrastructure by reducing surface runoff and enhancing water infiltration.

Effective management of water resources takes more than just savy price measures. Such measures are vital in changing the pattern of water use, but their full potential is realized only when complemented by strong infrastructure upgrades such as NbS-and greater public awareness. This holistic approach means that pricing rules are part of a greater strategy aimed at encouraging the sustainable use of water and enhancing resilience at the urban level, rather than merely acting as cost adjustment mechanisms. We can make sure that pricing policies successfully support long-term water conservation objectives and carry out their function in a sustainable urban water management framework by combining educational initiatives with infrastructure development.

6 Analysing Residential Water Demand and Political Influences

6.1 Analysing Residential Water Consumption Patterns and Their Political Context

The studies carried out between 2001 and 2003 show that, in general, residential water use accounts for about 73% of the public supply in the Centre region of Portugal and, therefore, is an important factor in the general panorama of water use. This increasing demand evidences the pertinence of the analysis of the variables influencing domestic water use, with special emphasis on the current framework of water scarcity and sustainable management.

In the towns under study, 98% of the population was served by water utilities in 2003, [63]. However, with an average of around 30 percent of the total water generated, network losses are a serious problem, [63]. These losses highlight inefficiencies that can jeopardize the long-term viability of the water system, both from an environmental and economic point of view. Adopting a multi-faceted strategy that uses various approaches is crucial for a better understanding of water consumption patterns. The integrated approach will therefore ensure that assessments consider not only the discrepancy in water use on different demographic groups, geographical areas, and seasons but also capture the breadth and depth of data required. Combining traditional methods with the latest technologies has the added advantage of enabling Water resource managers to obtain more and accurate data on domestic water consumption and hence come up with more effective policies and sustainable management strategies generally, [3], [64]. It ranges from the gathering of real-time data with the help of contemporary technologies to the analysis of historical consumption patterns. As an example, smart water meters and automatic

monitoring systems provide regular data flows that become necessary in identifying new consumption patterns and warning customers when urgent situations occur, such as leaks or unexpected peaks in usage, [65]. Furthermore, carrying out water audits and interpreting billing data allows for a much more homogeneous representation of consumption over time and for seasonal consumptions and the effects of water-saving to be more easily determined, [63]. Resident questionnaires can also be an important part of identifying attitudes and practices about water use since they give a qualitative view of water consumption that may point to causative factors of specific consumption patterns, [3].

An integrated approach of multiple techniques is necessary for solving the issues of water consumption and creating a reliable database. In this respect, this methodology also enables the water resource managers to foresee some circumstances and organize compensatory actions by changing the water management plans in order for them to adapt more effectively to the needs of the population and those due to environmental and economic variations, [3], [65]. It is by developing a better understanding of the trends in consumption that authorities can optimize the distribution of resources, improve the sustainability of water systems, and ensure universal access to clean and sufficient water. High domestic water consumption has wide implications for the environment, not only in the basic usage of a natural resource but also in affecting most aspects of the ecosystem and ecological sustainability. This quickly leads to overexploitation in regions either due to climatic constraints or over-extraction, thereby jeopardizing essential supplies, for example, aquifers and rivers. In addition to reducing the volume of water accessible for manufacturing and human use, this overexploitation severely deteriorates aquatic and terrestrial ecosystems that rely on these water supplies, [66], [67]. Secondly, since the treatment and distribution of water involve a colossal amount of energy use, high consumption is directly associated with increased energy use, which exacerbates global climate change due to the greenhouse gases involved in the process, [68]. Lastly, high demand exerts undue pressure on existing infrastructures, many of which were not designed to bear the load of demand experienced today, leading to frequent failures and inefficiencies. These problems result in substantial water losses and increased maintenance costs, requiring considerable investment in new infrastructure with notable environmental impacts, [69], [70].

Addressing water consumption issues requires the implementation of considerate behavior and effective management techniques that balance the needs of people, the conservation of natural resources, and environmental protection, [71]. Investments in water-saving technologies and thorough education on the need for water conservation are essential to minimizing negative environmental consequences and fostering a sustainable future, [72], [73]. As well as promoting efficient technologies and behaviors, politicians and utility companies should implement efficient water pricing methods and conservation programs, [69]. By encouraging changes in behavior, awareness programs are essential to reducing domestic water consumption and its environmental impact.

To maintain a balance between economic growth, social equality, and environmental sustainability, effective management of residential water consumption not only meets current demand but also safeguards these essential resources for future generations. Portugal can solve its water problems and make the transition to a more sustainable future by taking feasible measures.

6.2 Impact of Political Measures on Domestic Water Demand

Water demand management is also significantly influenced by political actions related to water pricing legislation. Decisions on tariff structures, such as the implementation of fixed or differentiated tariffs, directly affect how customers view and react to water tariffs, which in turn affects how they use the service. The Portuguese water tariff structure is complex, consisting of progressive tariffs and fixed quotas, even for the most sophisticated customers. It is not easy to explain to customers the financial consequences of their water use. How consistent and transparent the price signals that customers get depends on political practices that determine tariff-setting processes and may favor or hinder efficient water use.

In fact, some comprehensive studies have outlined relations between block tariff pricing policies and effective water demand control for Portuguese municipalities where such a method is applied. In fact, some comprehensive studies have outlined relations between block tariff pricing policies and effective water demand control for Portuguese municipalities where such a method is applied, [3], [22]. All this is about price elasticity, the ratio that defines the variation in demand for a product due to a change in its price. This is the well-documented price effect in the water sector, whereby a small percentage change in price can

even elicit fairly large quantities, in particular for those customers that are quite responsive to this type of price change. This is best brought out through the increasing block tariff structure, which increases the price per unit of water with increased use. This acts as a deterrent to overconsumption and pays for the ever-higher costs of providing larger and greater quantities of supply, [3], [65]. Consumer reactions to such pricing policies may quite vary with different socioeconomic and cultural factors. The poorer households can be more affected by price increases and adopt more parsimonious water use practices than higher-income households who are not as badly off financially by the higher tariffs. These differences in price sensitivity underpin the requirement of a pricing strategy that is appropriately calibrated within affordability, social justice, and environmental sustainability. It should also be complemented with clarity of communication on the part of municipal authorities and water companies while explaining to consumers how the creation of tariffs is done, and how their consumption patterns would have an impact on their water bills while such policies are in vogue, [63]. Education and awareness can foster a positive change in water use behavior. The education helps the masses understand why responsible consumption practices of water are important. Block tariffs are a strong tool in the field of water demand management, but this needs to be combined with complementary strategies that ought to include measures relating to the encouragement of uptake technologies that save water, investment in infrastructure so as to reduce water losses, and publicity for water conservation campaigns. This therefore provides an integrated platform in the management of water demand in trying to attain social obligations coupled with environmental sustainability and economic imperatives.

Modulation of domestic water demand is hence highly determined by pricing regimes, water sector governance, and regulation. Policymakers can create rules that balance affordability, conservation goals, and clarity of the pricing structure, highly influential in making household consumption patterns inducing and developing sustainable water management methods. The accompanying ones may be regulations that ensure favoring the application of water saving technologies, for example, requiring new installations of energy saving appliances either in new buildings or when the renovation is involved; these strengthen the policy and eventually reduce the per capita water consumption in number, [67].

The regulations can set minimum requirements about the equipment used in construction and the practices followed, making sure water-saving measures are taken up front in new buildings and their renovations. It saves water and makes builders and homeowners aware of the sustainability issues, [73]. These can be further expanded to include those policies that will create incentives for retrofitting the old properties with water-saving technologies through subsidies or tax credits to house owners for upgrading such systems, [74]. The large-scale water management regulations put the spotlight on the need of systems that promote water recovery and utilization. Moreover, there exist supportive infrastructural policies regarding greywater reutilization in urban areas to reduce pressure on natural supplies for a more 'sustainable' water cycle, [70].

The water industry rules must be applied fairly as well as effectively, and also, the regulatory bodies should have the authority, resources as well and other capabilities available to monitor compliance and be able to apply effective sanctions wherever necessary. Equally important, of course, is regular monitoring in that corrective measures may, in fact, be taken upon observations that policies may necessitate improvement. Good governance calls for openness and continuous dialogue that leads to the successful enforcement of policies, in turn translating into a change in domestic water use achieved through joint interest involvement among stakeholders: the customers, water utilities, environmental agencies, and greater part of the general public, contributing towards more realistic sensible usage of the water resource. If the regulatory and governance measures are well considered and put into place, it will go a long way in changing the domestic usage of water and bring forth a sensible utilization of water resources in a sustainable manner. These policies contribute to the attainment of long-term sustainable development goals and community resilience to increasing issues of water security, while addressing natural resource conservation.

Different complicated political issues, such as government policy and regulation or budgetary issues, do influence the implementation of water-saving activities in the Mediterranean cities. Of course, the development and success of any water conservation programs still depend on policy decisions made at the local, state, and federal levels. Besides the encouragement of efficient practices for water use, governments have powers and duties to pass favorable legislation and regulations toward this resource management, [74]. These include laws providing incentives for the installation of water-saving devices in residential and commercial

premises, regulations setting a minimum level of efficiency for applications involving the use of water, and even financial incentives to encourage the adoption of sustainable practices and enterprises [69]. Then, of course, there is financing and budget allocation-the supporting elements to make the programs effective. In fact, the successful implementation of water conservation programs depends upon the political will to commit adequate resources therefore, [73]. Due to a lack of funding, many projects are either never implemented or fail to reach their long-term goals and objectives. What financial support can make ranges from research and development of new technologies to community-wide education and outreach in shifting the public's mindset about what water conservation is. The other stakeholders include government organizations, non-government organizations, the commercial sector, and the involvement of local communities as another paradigm of political engagement in water conservation. These actors can work together to further strengthen the commitment in the spheres of society concerning water conservation. These can pave the way for the sharing of resources, best practices, and knowledge regarding this matter. Similarly, an effective water conservation strategy is needed within an integrated strategy that coordinates those efforts with other environmental and sustainability policies. For instance, water conservation strategies merged into the policies of environmental protection, urban planning, and natural resource management give a coherent framework that optimizes social and environmental benefits. These would need to be done responsively and transparently so that the ideal of building public trust and effective fund distribution are ensured. It would, therefore, be a much smaller scale but more frequent appraisals of performance and public reporting that would ensure the meeting of the conservation objectives sufficiently while programs adjust in relation to the shifting environmental conditions and population demands.

It can, therefore, be insisted that all considerations taken into account, cities in the Mediterranean and elsewhere can pursue effective water conservation programs that will address the urgent issues of shortage in the short term but also advance the sustainability of water resources eventually to serve present and future generations. In many Mediterranean cities, political practices have defined a wide range of demands for water from domestic consumption to other uses. With pricing strategies, the incentive for water conservation becomes bigger. On the other side, the more complex a pricing scheme is, the more it can be a source of confusion and hence has an effect on customers' reactions to certain price proposals. Financial incentives and subsidies that support the implementation of water-saving measures in the home or to the installation of water-saving devices are ways the policy tools could give incentives for water demand. Government-sponsored awareness initiatives also influence household consumption patterns by educating citizens about the value of water conservation and encouraging water-saving practices.

To achieve sustainable water management, policy practices and their direct impact on household water demand require thorough analysis and well-thought-out plans. Effective water demand management policies must also support sustainable practices that balance social justice, environmental preservation and economic needs.

6.3 Comparison of Political Implications with Political Considerations

The management of residential water demand in Portugal, namely under the block tariff regime, exemplifies the intersection between direct policy implications and the broader political considerations that shape pricing policies and their impact on domestic water consumption.

The above-mentioned studies show that water pricing is a useful instrument for rationalizing use, despite low-price elasticities. Higher prices can incentivize conservation and the efficient use of water. However, progressive block tariffs raise significant equity concerns, as they penalize larger families who naturally tend to consume more water, [74]. These tariffs need to be carefully considered to ensure they do not conflict with the universal service requirement, which is to ensure that everyone has access to the minimum amount of water necessary for human survival. However, the increase in the cost of water to meet demand should not come at the expense of universal service, which guarantees that everyone has access to the minimum amount of water necessary for survival. This strategy draws attention to a major enigma in water management: how to find a balance between the demands of conserving resources and ensuring equitable and adequate access to these same resources. Policymakers must take into account a number of variables that can make implementing water price regulation more difficult or easier. Customers can be confused by the signals of inertia and conflict that tariff structures – such as the competitive application of flat rates and block rate increases – give off, endorsing demand pricing

capabilities, [74]. It would, however, increase the effectiveness of demand-based pricing. If consumers better understand how their consumption determines the cost of water, then the price systems should be transparent and unequivocal. The use of proper pricing policies in the Portuguese water industry could be encouraged by giving the powers to intervene and manage the possible conflict between the objectives of efficiency and equity during the price-setting process to the regulatory bodies themselves, [17]. The tariff measures should be accompanied by awareness creation, education, and promotion of efficient water-use technologies as part of non-tariff measures in the management of water demand, [73].

In water management, politicians must consider various variables, as already evidenced by the policy implications and considerations analysis. Cities can promote sustainable water consumption and still achieve universal access to this essential commodity through the removal of pricing structures' complexities, granting regulatory bodies more powers, and the adoption of a mix of tariff and non-tariff policies, [17], [74]. This is because, as various studies have suggested, the ability to understand the dynamics at play here is important in developing strategies that take into consideration both the immediate impacts and wider ramifications of political consequences, [75], [76]. For example, governments whose political orientations are more inclined toward liberal politics would normally have little impact on conservation as there is a high reliance on free-market dynamics, while those where the preponderance of political orientation is socialist usually enact strict policies of water conservation, [76]. In this regard, it is further recognized that political decisions have to do with all aspects of water management. It corresponds with an extraordinarily complex balancing act between short-term goals, such as economic growth, and long-term sustainability goals that are imperative for effective and just water management, [73].

Efficiency, equity, accessibility, and transparency-these are the big four in the realm of policymaking. The balance among these four will definitely go a long way toward producing policies that ensure residential water demand is kept within check and encourage the sustainable use of this resource. It will also mean that at least the equity issues are sorted out in a way that everyone has access to this life-giving resource. Keeping in mind these complex dynamics, an egalitarian and ecologically sound future can be ensured by Portugal regarding its water resources.

7 Policy Recommendations

7.1 Recommendations for Improving Water Demand Management Strategies at Municipal Level

Ecological balance, protection of water supplies, and populations continuing to have access to drinking water depend on the municipalities' effective management of water demand. Population expansion thus, coupled with increased urbanization and the effects of climate change placing an additional burden on water management systems that are now in place, will exacerbate this problem. Policies to create more sustainable and rational usage of water must be developed and implemented in order to manage these issues in a proactive manner. Main recommendations include reformulation of pricing methods, promotion of water-efficient technologies, integration of water and sanitation tariffs, educational programs, and advanced analytics.

Indeed, the Municipality informs that appropriate financial incentives for water-saving practices can be passed through the implementation of progressive and transparent tariff structures. Furthermore, this approach provides non-discriminatory pricing that correctly reflects the full cost of water supply and waste treatment services, while at the same time promoting waste reduction. The second important measure is the promotion of water-saving devices. Municipalities can allow rebates and other incentives that provide families with access to such technologies as smart irrigation systems, low-flow toilets, and efficient showers. Such technologies reduce overall water use with no degradation in comfort or inconvenience to the customer.

Instructional initiatives are required to raise awareness and changing customer behavior. These should thus be holistic campaigns and must include various forms of platforms such as social media, radio, television, and community activities. The partnerships may also deepen the work by introducing water conservation education in school curricula, and events organizing with local organizations, universities, and schools. With actionable recommendations, like installing devices for flow reduction, or turning off the tap while brushing teeth, water conservation could become tangible and realistic for the common man. Such initiatives can help grow a sustainable culture and prudent use of water, besides spreading awareness amongst the masses on the importance of water conservation.

Combining water and wastewater rates into one fair and effective pricing structure would encourage responsible habits in using the service. Municipalities might ensure that supply and treatment costs are represented in the pricing structure while assessing water and wastewater tariffs simultaneously. In this way, the combination of better equity and sustainability of water management is combined with a reduction of less welcome outcomes from cross-subsidies where other users could be subsidizing others' overuse. With this method, municipalities have ease in managing their water supply, since the operational efficiency is high and the procedures for billing are simplified.

Big Data and artificial intelligence are examples of more sophisticated analytics that can greatly enhance the ability to track and control water consumption. These solutions can enable deep analysis of consumption trends, prompt detection of problems like leaks or other spikes in usage, and the treatment thereof. With advanced analytics, municipalities will be able to strengthen resiliency within water management systems, allowing for more sustainability and efficiency in water consumption.

Implementation involves coordination at the level of local communities, the commercial sector, and government agencies. Such collaboration will ensure that the policies enacted indeed serve the purpose effectively, and equitably, and address the specific needs at the level of the individual municipalities. The municipal entities will, in turn, contribute to water supply sustainability and operational cost reduction while fostering a collaborative approach whereby demographic perceptions are matched with policy initiatives for environmental conservation. These recommendations are an initial input into discussing a water management policy for sustainability in Portugal and should form the basis upon which the government drafts legislative and regular measures toward the efficiency of resource management and long-term environmental sustainability.

The Portuguese municipality can hugely develop a better water demand management strategy, reformulation of pricing models, promotion of water-efficient technologies, launch educational campaigns, integrate the tariffs of water and sanitation, and use of advanced analytics. By so doing, communities will be made more resilient to the challenges that future population growth, urbanization, and changes in climate will bring. They will be contributing to better use of water resources and reduce the environmental impact of water utilization.

7.2 Policy Recommendations to Encourage Private users Towards the Sustainable Use of Water

It is a reality with comprehensive policy measures concerning tariff reformulation, utilization of advanced technologies, and education for efficient demand management and responsible residential consumer consumption, [63], [69]. Tariffs should promote conservation, increasing gradually in proportion to the quantity consumed and being clear enough to encourage behavioral adjustments, [3], [63]. Smart meters and other cutting-edge technologies enable real-time usage monitoring and automatic adjustments to water usage, increasing efficiency, [64]. Conservation techniques and the value of protecting water resources should be included in educational programs and awareness campaigns should be widely published, [65]. Water-saving products can be promoted and incentivized programs, such as bill reimbursement for sustainable practices, can be developed through partnerships with local businesses and non-governmental organizations. Coordination between government agencies and stakeholders is important for implementing these policies, and strategies should be regularly evaluated and adjusted as necessary, [67]. The comprehensive and integrated strategy can drastically change household water use, resulting in more sustainable management of water resources and improving community environmental resilience.

Encouraging residential consumers to use water sustainably requires the adoption of clear tariffs. Clear tariff structures make the consumer act responsibly in adjusting consumption because they can clearly see how changes in their consumption will have an effect on their bill. Progressive tariffs, where the percentage of consumption increases, avoid wastefulness and costs are in line with sustainable practices. In these kinds of rates, low-income consumption is also protected by increasing basic access at a reasonable price and additional rates for excessive use. Successful marketing in the tariff structure reinforces the adoption of water-saving measures. The authorities encourage more sustainable use of water in residential communities by making people aware of the value of water conservation and its consequences on the environment and economy, [63], [69].

It is relevant to encourage water-saving technologies with financial incentives for residential users to consume more sustainably, [63], [69]. To

reduce domestic water consumption, tax incentives are needed, along with rebates and subsidies for installations of technologies like smart irrigation systems, dual-flush toilets, and low-flow showerheads, [3]. Such technologies are more profitable due to the fact that in addition to consuming less water, they combine financial incentives with environmental goals, [5]. Financial incentives enhance the understanding of customers in accruable benefits from their decisions, [73]. Collective responsibility for water conservation is reinforced by educational efforts that include practical demonstrations, [77]. Providing incentives for these technologies also encourages research and market development, which increases water use efficiency and the green economy, [65]. These actions support sustainable development and are beneficial to the economy, consumers, and the environment, [64]. To ensure that water resources are preserved for future generations, it is essential to establish a culture of long-term water conservation, [63], [69].

Promoting sustainable water use practices requires implementing effective educational initiatives. These advertisements should draw attention to the harmful effects of excessive consumption and demonstrate how small behavioral adjustments can result in significant cost reductions, [71]. They force public commitment to conservation when combined with the commercialization of water-saving technologies, [5], [77]. Messages are guaranteed to reach a wide and varied audience when a variety of communication channels, including radio, television, and social media, are used, [75]. The local community is inspired by community events that provide opportunities for face-to-face communication and discussions about water conservation, [4]. In order to prepare a new generation to adopt sustainable behaviors, partnerships with educational institutions and schools to include water education in curricula are crucial long-term solutions, [3]. These initiatives can be expanded through collaborations with NGOs and government organizations, resulting in visual and motivating campaigns that encourage long-term adjustments in water use habits, [78], [79]. These initiatives promote community dedication to safeguarding water resources for future prosperity and provide information [2], [73].

Water management is being transformed by technology, making it an interactive tool to promote awareness. Monitoring consumption in real-time using smart meters promotes waste minimization and judicious management of water resources, [64]. These cutting-edge tools uncover leaks and inefficiencies by identifying usage patterns, [65]. By providing individualized conservation advice and notifications for unforeseen usage spikes, mobile apps, and web platforms improve the user experience. To save water and effectively care for plants, sensor-controlled irrigation systems modify water use in response to actual environmental circumstances, [80]. These technologies will help in promoting environmental habits in a natural and accessible way, putting them into the daily consumers' lives. Practicing this adoption, it will eventually strengthen environmental sustainability by saving a large amount of water over time. In this context, the technology provides greater efficiency not only in water but also creates shared responsibility to secure this important resource for the survival of international communities, [73], [78].

To coordinate the policies of sustainable water use, these tariff structures need to be updated and revised [69]. Given the treatment and distribution costs, infrastructure maintenance, and resource management, tariffs are designed to reflect the operation costs and foster good conduct, [63]. For a prudent use of water, there is a need to consider environmental costs that provide its ecological value and scarcity, [67]. The tariff variation should clearly include incentives for good sustainable behavior, such as fines for overconsumption and discounts for those who are mindful of their use. Transparency and involvement of all the stakeholders, including consumers and environmental organizations, engender greater acceptance and understanding of policies and changes to them. Continuous community input would instil confidence in the fare system and provide further refinement of areas that are still in need of adjustment. It requires a balancing act in charging for the costs of water supply while discouraging poor water use practices if the supplies are to be financially and environmentally sustainable. The rates should, from time to time, be reviewed, taking into consideration all the environmental costs to try and influence consumption in a sustainable manner and ensure this resource continues to be available to future generations.

In this direction, political coordination for sustainable use can enable Portuguese municipalities to establish an adequate consideration and effectiveness culture in the use of water resources. Such a broad policy will stimulate appropriate water management to respond to present needs and diminish future complications with the scarcity of water and environmental preservation. Development of advanced technologies, reforming the current tariff regulations, and public education

about the importance of savings will make municipalities leaders in this sector, [5]. In order to create a strong coalition for water sustainability, the integrated approach places a strong emphasis on cooperation between government, business, academic, and civil sectors, [71]. With active consultation and feedback on water management, transparent and participatory government increases public trust and engagement, [77]. Creating new technologies and approaches to water conservation that increase resilience to climate issues depends on strategic partnerships for research and innovation, particularly with universities and research centers [64]. Future generations will be educated through ongoing educational initiatives that focus on conserving aquatic habitats and using water efficiently, which encourages a shift in culture around water sustainability. When combined, these actions make water management in Portugal a model of sustainability, showing that growth can coexist with environmental preservation and conservation of natural resources, and can serve as a model for other nations, [67].

7.3 Strategies to Involve Stakeholders and Promote Political Consensus on Water Conservation Measures

To face future challenges of water scarcity and responsible environmental management, Portuguese municipalities adopt a holistic approach that integrates coordinated strategies for the sustainable use of water, ensuring long-term efficiency in the management of water resources, [66]. This requires collaboration between local governments, companies, communities, and NGOs, committed to robust water conservation and efficient use policies, [71]. Integrated management maximizes water efficiency through advanced technologies, recycling and reuse practices, efficient irrigation systems, and treatments that minimize waste and preserve aquatic ecosystems, [65]. Educating and raising awareness among the population is essential to promote responsible and ecological behavior, [77]. Educational programmes in schools are effective in training conscious new generations. Dedication to water sustainability is strengthened by explicit government policies such as progressive pricing, subsidies for effective equipment, and strict restrictions, [63]. By using these tactics, Portuguese municipalities ensure that current water resources are managed effectively and are prepared for a sustainable future that benefits nearby ecosystems, economies, and communities, [67].

To ensure that chosen policies represent a wide range of opinions and requirements, it is imperative that different stakeholders are included in water conservation activities, [78]. Incorporating citizens, neighbourhood associations, water suppliers, environmental organizations, and policymakers improve the decision-making process, reinforces dedication and cooperation across many sectors, and promotes creative and widely accepted solutions, [81]. People affected by policies can express their ideas through public forums and consultations, which facilitates two-way communication between the government and the public, [71]. This inclusive strategy increases implementation effectiveness by promoting openness, trust, and reduced resistance, [79]. By the founding agreement through these exchanges, water conservation efforts are guaranteed to be based on shared understanding and dedication of the group, [81]. This collaboration between the local needs and the long-term sustainability goals allows for the enhancement of community resilience and sustainable management of water resources. In addition, this also gives a promise of success of policies, [71]. Strategic synergy between different stakeholders creates a strong network of cooperation that robustly increases the development of more resilient and sustainable communities, [78].

Education and awareness programs are valuable tools in providing emphasis on the value of water conservation and long-term sustainability practices that have tangible advantages to society. The practice and values derived from these programs result in long-term benefits to society by showing accountability and concern for all parties involved. These programs encourage important behavior modification through the education of all participants, including major companies and governments, down to the individual customer, [54]. Community education fills the public with awareness for conscious water resource use, builds knowledge, and strengthens individual and group responsibility in this respect, [78]. Policy discussions ensure that all opinions are heard, and disputes are resolved, incorporating a cooperative atmosphere for sharing ideas and creating successful water conservation programs, [71], [81]. A culture of conservation that transcends legal compliance and becomes rooted in social and corporate ethos is promoted by these campaigns and political discussions, [54]. It is feasible to ensure that water sustainability safeguards and benefits communities, promoting health, prosperity, and environmental sustainability for present and future generations, through the inclusion of continuing education and open discussion in organizational and municipal policies.

Capacity building is essential for sustainable water management because transformative education equips stakeholders to adopt proactive measures by disseminating information about relevant policies, technologies, and strategies, [71]. These programs provide people with the tools they need to effectively participate in water conservation decisions, [81]. To increase the impact of water conservation programs, intersectoral cooperation between communities, businesses, NGOs, and government organizations is essential, [78]. Successful collaborations bring together resources and knowledge, which promote creative solutions that help communities and the environment, [71]. Municipalities and organizations support an integrated and sustainable approach to water management by coordinating educational initiatives and strategic alliances, [77]. To achieve the goals of efficient and sustainable conservation [78] and protection of water resources for future generations [81], coordination between the business sector and various levels of government is essential.

To build trust and encourage community involvement in public policies, transparency, and high communication are essential in water management, [71], [78]. For conservation initiatives to be successful, transparent decision-making procedures must keep all parties informed and participatory, [77], [81]. Proactively promoting advances, difficulties, and results through open communication allows the community to understand the consequences of their actions, [78]. This continuous feedback strengthens dedication to sustainability, creating a positive feedback loop that leads to better policies, [71]. Maintaining open lines of communication is essential for long-term sustainable water management because it ensures community support for conservation efforts, [77], [81]. The foundations of collaboration and sustainable water management are transparency and community involvement.

In order to satisfy immediate demands and long-term advanced practices, policymakers lay the foundation for resilient and sustainable water management by implementing deliberate measures to engage stakeholders and promote political agreement, [71], [81]. By promoting traditions that will be passed on to future generations, this inclusive strategy establishes community water sustainability, [77], [78]. By reaching an agreement, the cooperative method is a culture of environmental management and increases community resilience, [71]. Sustainable water management is an inherent community value when people are involved in each phase of conservation policy development, [77]. Conservation practices are encouraged, and more efficient management of water resources is promoted through increased knowledge of the environmental effects of water-related activities, [71], [81]. Next, it is feasible to change the way people view and use water and ensure its preservation for future generations, making sustainable water management a commitment to these social values, [77], [78]. In addition to meeting current needs, this change creates a legacy of preservation and care that benefits the environment and future generations.

8 Conclusions

The study examined water savings, highlighting the main drivers of demand and the consequences of pricing strategies. The study found that meteorological, sociodemographic and economic factors significantly impact water consumption. In particular, although income, population density, average annual temperature, and annual precipitation were not statistically significant, the percentage of older individuals and average household size explained residential water use.

Demand for water is often inelastic, meaning changes in price have a negligible effect on usage, according to research on pricing strategies. However, the study made it clear that pricing tactics such as increasing block rates and seasonal pricing can be useful in controlling water demand. For example, large consumers have been incentivized to save water through the rising global tariff, which increases the price of water per unit based on consumption levels. Water use has also been successfully decreased through the introduction of progressive charges such as IPT, especially for large users. Especially in Lisbon, the awareness campaigns reduced domestic consumption by 20% in just five years. As happened to the city of Albufeira, which reduced its consumption of water by 15% during the summer, seasonal pricing has been equally effective. Together with educational campaigns, such measures substantially cut household water consumption and raised the installation of water-saving devices.

Complementary measures to pricing strategies, like public awareness campaigns and investments in water efficiency technologies, would be equally crucial. Such complementary strategies also foster more sustainable and reflective consumption of water that may further strengthen the effectiveness of pricing regimes. Water management is also greatly dependent on political forces and policies. If the latter are to respond successfully to people's

needs, they must consider consumption patterns. Hence, a multi-dimensional approach in analysing consumption patterns across different time horizons calls for many methodologies using modern technology, especially in real-time data collection. Such data can be collected through devices like automatic monitoring systems, smart water meters, and the like. During crises, when poor families need to make at least an amount for subsistence, well-balanced water pricing policies become preconditions that make sure of social justice, access, and environmental sustainability. Local authorities have to communicate in an easy and effective way for residents to understand the rate structure and, as a consequence, making better decisions about the saving of water while viewing their bills. It can take many routes, from liberal governments that may prefer a free market to more socialist regimes imposing longer-term water conservation regulations. The inference here is that political balance between short-term demands and long-term goals is fundamental in approaching an equitable water management plan. It will support responsible water consumption through fiscal incentives, especially for buying certain technologies beyond the budgets of some homes, such as smart irrigation systems, low-flow toilets, and showers. Dynamic tariffs will be established, taking care to reflect local and seasonal needs, while continuing and intensifying public awareness campaigns. Policies integrating these changes in climate and population will also be essential in supporting long-term sustainability of the water resource base. Co-operation among different levels of government and sectors of society is necessary for effective plans that strike a balance between sustainability, equity, and efficiency in water use. While the business sector and civil society are fundamental with respect to the implementation of sustainable inventions and practices, it is the collaborated effort of the local, regional, and federal governments that must establish policies to conserve resources. This will help to ensure that the various policy mechanisms do not disproportionately affect disadvantaged groups by being unnecessarily costly or inefficient.

It is true that technological advances and progressive tariffs might secure water efficiency, but equity necessitates taking account of the different abilities to pay regarding communities when the policies are made. On the contrary, sustainability depends on the cooperative measures that manage natural resources and encourage their use responsibly. Without this cooperation, water management will not be able to guarantee this availability of these basic resources, along with their accessibility, in an efficient and equitable manner for the current as well as future generations.

The development of water conservation goals is combined with ecological and economic sustainability through transparency and coordination between the different executive bodies and the private sector. Without this collaboration, this goal would not have been achieved-or at least, not thoroughly-of having water reach Portuguese families' homes, especially in less urban settings.

It shows several points that are priceless to estimate the various factors' influences on water demand and the efficiency of price strategies. Data gathered from various municipalities in Portugal shed light on the main socio-economic and demographic factors that affect water consumption at home. Factors like house size, age of residents, income levels, and population density all proved significant in estimating variation in water demand. As an example, cities with higher population density generally have lower per capita water use since there are fewer green areas or gardens to be irrigated, while larger families generally use more water. Such outcomes are essential for creating more targeted and successful public initiatives. It is possible to create pricing strategies that not only incentivise the preservation of water resources, but also promote equity in access by understanding how factors such as income or age distribution influence water use. It is possible to change progressive pricing regimes, such as the block pricing system, to promote more environmentally friendly behaviour without unduly burdening vulnerable demographic groups. Furthermore, in-depth knowledge of the factors that influence consumption allows for the implementation of water efficiency initiatives and awareness campaigns that directly address the unique socio-economic characteristics of each area, maximising the impact of government interventions. Furthermore, analysing the inelasticity of demand highlights the need for comprehensive strategies that go beyond simply changing prices to promote water conservation. Future research could further analyse variables that were not statistically significant in this study, such as income and population density, to better understand their possible indirect influences on water consumption. In addition, we recommend further research into the effectiveness of different pricing models in different socio-economic contexts. It would also be relevant to analyse the impact of climate change on water resources and explore new water conservation technologies and practices. Finally, it could also be beneficial to explore the impact of new water management technologies and

conservation methods in different regional and climatic contexts.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and have not utilised artificial intelligence (AI) tools. The authors take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

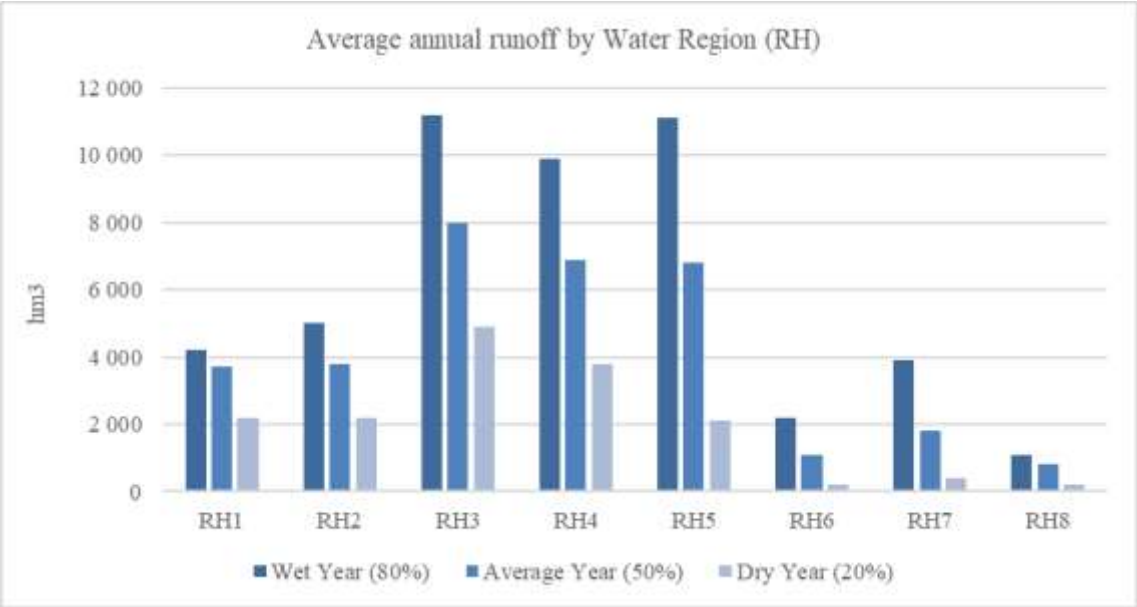

Fig. 1: Average annual runoff by Water Region (RH)

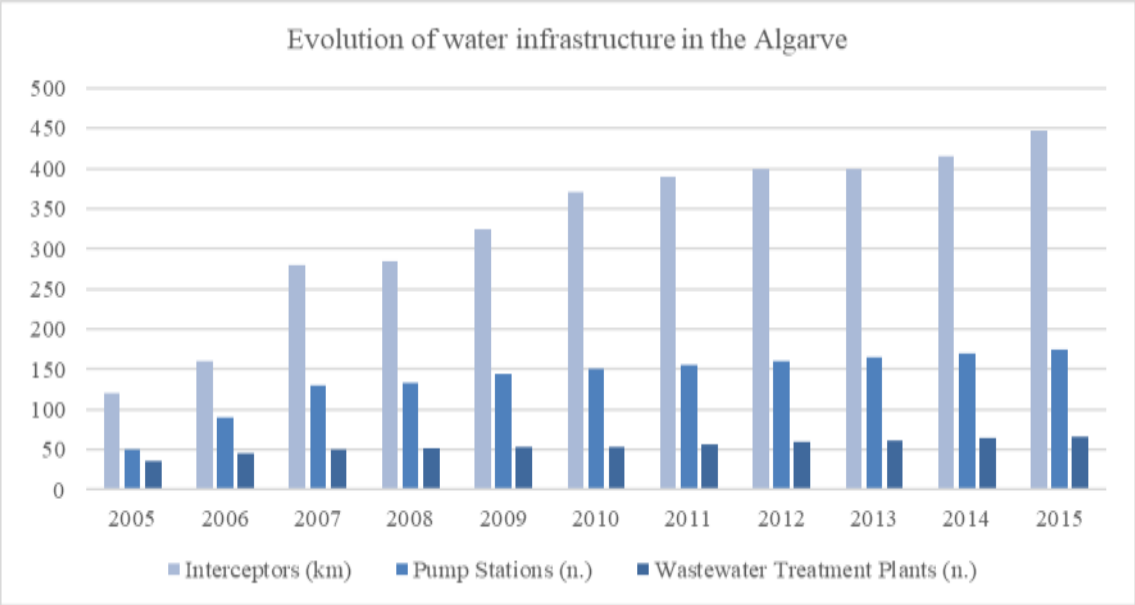

Fig. 2: Evolution of water infrastructure in the Algarve

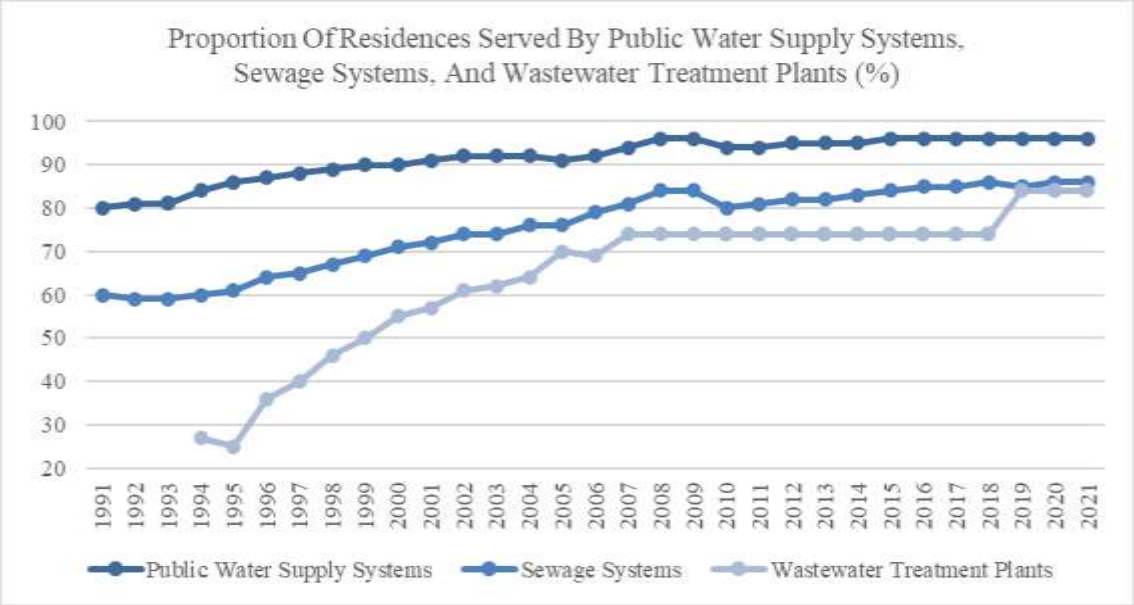

Fig. 3: Development of water infrastructure in Portugal

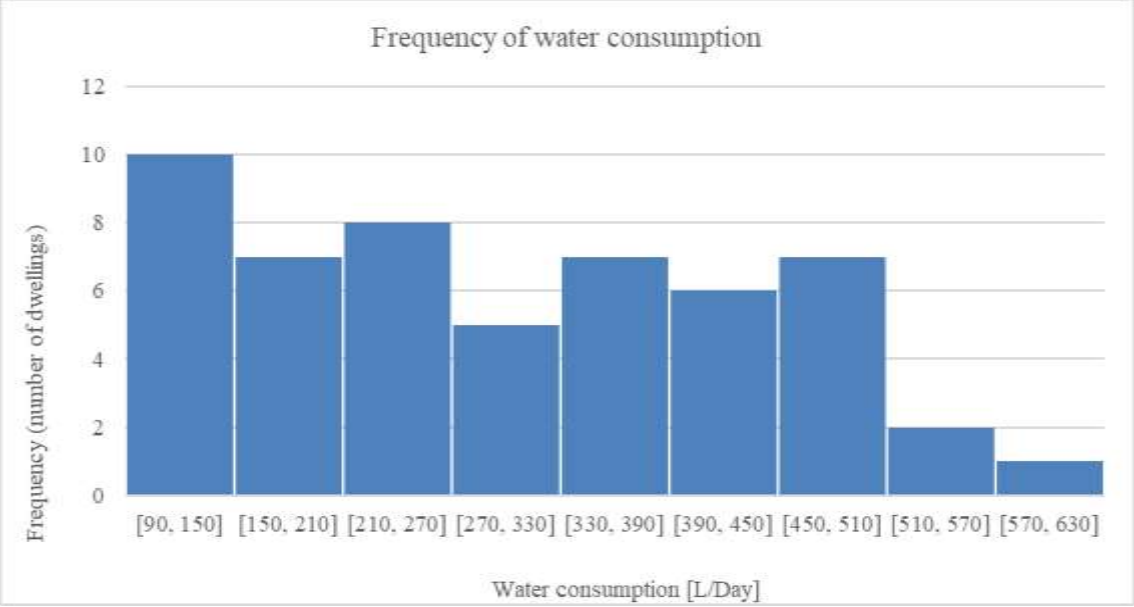

Fig. 4: Frequency of water consumption

Table 1. PENSAAR 2020 Vision and Strategic and Operational Objectives, [21]

A sector at the service of the population and the economy of the country that provides quality and sustainable services in environmental, economic-financial, and social terms				
Development of the sector based on governance in partnership and supported by strategy				
Axis 1 Environmental protection and improvement of the quality of water bodies	**Axis 2** Improvement of the quality of services provided	**Axis 3** Optimization and efficient management of resources	**Axis 4** Economic-financial and social sustainability	**Axis 5** Basic and transversal conditions

Table 2. Description, Expected Interpretation, and Estimated Result of the model coefficients

Coefficient	**Description**	**Expected Interpretation**	**Estimated Result**
$\beta 1$	Coefficient of the average monthly income of workers (Rend*it*)	It is expected to be positive. An increase in the average monthly income of workers leads to an increase in residential water consumption.	0.000924 (not significant)
$\beta 2$	Coefficient of the percentage of elderly people (Idos*it*)	It is expected to be positive. A higher percentage of older people is associated with higher water consumption.	429.9266 (significant at 5%)
$\beta 3$	Coefficient of average household size (Numres*it*)	It is expected to be positive. Larger households tend to consume more water.	59.08764 (significant at 5%)
$\beta 4$	Population density coefficient (DenPop*it*)	It is expected to be negative. A higher population density indicates less green space, such as gardens and backyards, reducing the need for water for irrigation.	−0.0008783 (not significant)
$\beta 5$	Average Annual Temperature Coefficient (Temp*it*)	It is expected to be positive. Higher temperatures increase water consumption.	4.777432 (not significant)
$\beta 6$	Annual Precipitation Coefficient (Prec*it*)	It is expected to be positive. Higher rainfall can increase residential water consumption, especially in urban environments.	−0.0072627 (not significant)