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Sustainable Water Management: Understanding the Socioeconomic and Cultural Dimensions

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Abstract: With the pressing challenges of water scarcity and pollution, achieving sustainable water management is imperative for promoting long-term development. Therefore, this paper aims to examine the socio-economic and cultural factors that shape the sustainability of water management strategies in Brazil and Portugal. This study highlights various factors that influence water management, including robust legal frameworks, socio-economic disparities, cultural practices, agricultural water usage, knowledge sharing, public participation, climate change resilience, water scarcity risks, industrial water consumption, and urbanization. By conducting a SWOT analysis of water management strategies, this research synthesizes information through an extensive literature review, encompassing the legal frameworks, policies, and implemented strategies in both countries. Additionally, it investigates comparative studies among Brazil, Portugal, and other European nations to facilitate the exchange of knowledge and experiences in water management practices. The findings of this study offer valuable insights into the strengths, weaknesses, opportunities, and threats associated with water management strategies in Brazil and Portugal, thereby guiding the development of tailored policies and strategies that foster sustainability in water resource management. Additionally, the research highlights the role of digital transformation in optimizing water management practices. By integrating socio-economic, cultural, and digital factors, this study contributes to effective and sustainable water management in Brazil and Portugal, ensuring responsible utilization and preservation of water resources.

Keywords: water scarcity; treated wastewater reuse; sustainable water management; socioeconomic factors; digital transformation; cultural practices

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1. Introduction

Water resource management is a paramount global concern, particularly in light of escalating water scarcity, climate change impacts, and the urban population [1]. Effective water management strategies are pivotal to ensuring equitable distribution, sustainable utilization, and conservation of this indispensable resource [2]. The distinct geographical, climatic, and socio-economic landscapes of Brazil and Portugal create unique water management challenges for these nations [3,4]. Despite the steps taken by both Brazil and Portugal to formulate policies and initiatives addressing these challenges [5], there persists a need to explore potential gaps and limitations within their water management practices.

The interplay between socio-economic and cultural factors and the digital transformation in water management is a subject that highlights opposing arguments, shedding light on potential benefits and challenges in Brazil and Portugal. This discussion aims to delve into these contrasting perspectives, offering insights into the complexities of water management in these regions.

On the one hand, there exists a research gap in understanding the integration of socio-economic and cultural factors with the digital transformation in water management [6]. By bridging this gap, valuable insights can be gained, allowing digital tools to be effectively harnessed to enhance water management while being mindful of the socio-economic and cultural contexts of Brazil and Portugal [7]. Contrastingly, if strong legal frameworks are not established to guide water management strategies, the effectiveness and sustainability of these approaches could be undermined [3]. The absence of clear regulations and guidelines could result in inconsistent water allocation, a lack of accountability, and disputes among stakeholders [4]. This lack of legal structure might fragment efforts and impede coordinated actions for equitable and responsible water resource management [5]. Similarly, considering socio-economic disparities, cultural practices and public participation are pivotal in water management strategies [6]. In a scenario where these factors are overlooked, challenges in water access, distribution, and conservation could arise, disproportionately affecting marginalized communities [7]. Unsustainable cultural practices and insufficient community engagement could further exacerbate these challenges [8]. Additionally, disregarding agricultural and industrial water use practices in water management strategies could have severe consequences [9]. Failure to manage these sectors properly could lead to water overexploitation, scarcity, and ecological degradation [10]. Inadequate regulation might strain resources, impacting water availability and aquatic habitats [11]. Addressing climate change resilience, water scarcity risks, and urbanization is essential for effective water management [12]. Neglecting these challenges could intensify water scarcity, pollution, and urban demand [13,14]. The absence of long-term planning and sustainable land use practices might compromise water quality and preparedness for future crises [15]. On the other hand, the advent of digital technologies, such as IoT devices, data analytics, and real-time monitoring systems, offers the potential to transform water management [16]. These technologies can enhance efficiency, detect leaks early, optimize distribution, and improve decision-making [16]. Contrasting this with a scenario where digital transformation is absent, it can be argued that managing water resources and mitigating scarcity would be considerably compromised. However, the integration of digital solutions raises concerns. While promising, unequal access to these technologies could exacerbate socio-economic disparities [17]. Cultural attitudes towards technology also play a crucial role. Without considering cultural factors, resistance or mistrust towards new technologies may hinder successful integration [18]. A counterfactual argument could explore the potential hindrances to successful technology adoption due to the absence of culturally sensitive approaches.

The opposing arguments emphasize the intricate relationship between socio-economic and cultural dynamics and digital transformations in water management strategies. Integrating these elements can lead to more effective and sustainable approaches; however, neglecting them might exacerbate challenges and inequalities. Balancing these factors is crucial for crafting holistic water management strategies that ensure both resource conservation and social equity. Hence, this article comprehensively examines the water management strategies in Brazil and Portugal, aiming to identify key factors influencing their effectiveness, encompassing socio-economic, cultural, and digital aspects. The objective is to shed light on the strengths, weaknesses, opportunities, and threats associated with these strategies, facilitating the development of context-specific improvements for sustainable water resource management. In this framework, the research question is:

How do water management strategies in Brazil and Portugal compare, and what are the underlying factors influencing their effectiveness?

Accordingly, the following hypotheses are formulated:

Hypothesis 1 (H1). *Strong legal frameworks positively influence water management strategies, leading to more effective and sustainable approaches.*

Hypothesis 2 (H2). *Socio-economic disparities, cultural practices, and effective public participation significantly affect water management strategies, leading to challenges in equitable access, distribution, and conservation of water resources.*

Hypothesis 3 (H3). *Agricultural and industrial water use practices have a considerable influence on water management strategies, impacting water consumption, sustainability, and environmental impacts.*

Hypothesis 4 (H4). *Climate change resilience, water scarcity risks, and urbanization significantly impact water management strategies, necessitating proactive measures, long-term planning, and sustainable land use practices to mitigate negative effects on water resources.*

This paper is structured as follows: It begins by outlining the study design and methodology, followed by an examination of the water scarcity challenges in Brazil and Europe. The complexities of water management and collaborative strategies are discussed, along with an analysis of socio-economic factors, cultural factors, and digital transformation. A SWOT analysis is conducted to evaluate water management strategies in Brazil and Portugal, leading to a comprehensive conclusion that synthesizes key findings and insights.

2. Materials and Methods

This study employs a multifaceted methodology that integrates qualitative analysis, comparative assessment, and data synthesis to offer comprehensive insights into the intricate landscape of water resource management strategies. The ensuing subsections elaborate on the data sources, analytical criteria, and methods utilized throughout the study.

Data Collection and Sources: The data for the literature review and SWOT analysis were collected from secondary sources, including the United Nations database [19] (https://www.sdg6data.org, accessed on 1 July 2023) and the climate change knowledge portal [20] (https://climateknowledgeportal.worldbank.org/country/portugal, accessed on 1 July 2023), as well as policy documents and legislation such as the National Water Resources Policy in Brazil, the Water Framework Directive in the EU, and the Water Law and PENSAARP 2030 in Portugal. These sources provided information on legal frameworks, policies, institutional arrangements, and specific initiatives implemented in Brazil and Portugal.

Qualitative and Quantitative Analysis: The gathered data underwent a dual approach for qualitative and quantitative analysis, enriching the research with meaningful observations. The data from the literature review underwent a thematic analysis to unearth key themes and patterns pertaining to water management strategies in both countries. This approach facilitated the identification of overarching trends and challenges within the context of water resource management. Concurrently, the SWOT analysis involved categorizing the strengths, weaknesses, opportunities, and threats identified, followed by a thorough examination of their interrelationships. This combined methodological approach facilitated a holistic comprehension of the intricate dynamics surrounding water management in both Brazil and Portugal.

Key Criteria for Analysis: To ensure a comprehensive analysis of water management policies, this study delineates key criteria that significantly influence the efficacy of water resource management. These criteria encompass legal frameworks, integrated approaches, resource utilization efficiency, public participation, climate change adaptation, socio-economic disparities, cultural practices, agricultural water use, industrial impacts, urbanization challenges, and collaborative initiatives. These established criteria form a comprehensive framework for evaluating the strengths and weaknesses of water management strategies in Brazil and Portugal.

Comparative Analysis: A comparative analysis was executed to discern commonalities and disparities in water management policies and challenges across Brazil, Portugal, and EU countries. This comparative approach facilitated the identification of best practices,

avenues for knowledge exchange, and areas necessitating improvement. The assessment was grounded in a systematic review of policy documents, legislative acts, and practical initiatives within the respective regions.

Qualitative Assessment: Qualitative assessments were conducted to gain deeper insights into the influence of socio-economic and cultural factors on the effectiveness of water management in Brazil and Portugal. These assessments involved scrutinizing economic development indicators, political governance structures, institutional cooperation mechanisms, public awareness campaigns, and societal attitudes toward water and the environment. The qualitative data were amalgamated to uncover underlying trends, obstacles, and potential remedies concerning water resource management.

SWOT Analysis: Employing the SWOT (strengths, weaknesses, opportunities, threats) analysis framework, an evaluation of water management strategies in Brazil and Portugal was conducted. This assessment aimed to elucidate both internal and external factors that impact the efficacy of these strategies. Strengths and weaknesses were deduced from the characteristics inherent in the water management systems, such as legal frameworks, institutional arrangements, and implementation methodologies. Opportunities and threats were gauged by considering external factors such as socio-economic disparities, cultural practices, agricultural and industrial water use, urbanization dynamics, climate change resilience, and water scarcity risks.

Interdisciplinary Approach: This study adopts an interdisciplinary approach that amalgamates insights from diverse domains, including environmental science, law, economics, sociology, and technology. This all-encompassing approach facilitates a comprehensive evaluation of water management policies that accounts for both technical and socio-economic dimensions.

By employing a combination of qualitative analysis, comparative assessment, and data synthesis, this study provides informed insights into water management policies and challenges. The methodology allows for a comprehensive evaluation of the complex factors that shape water resource management strategies in Brazil, Portugal, and European Union countries. The findings contribute to the understanding of effective water governance and sustainable resource utilization, while also highlighting opportunities for collaboration, knowledge-sharing, and policy improvement across regions.

3. Water Scarcity Challenges

Water has been regarded as an abundant and inexhaustible resource. However, only 2.5% of the Earth's water constitutes freshwater [21], which is vital for the survival of various species, while a mere 0.3% is available for human consumption [21]. The accessibility of freshwater is severely restricted due to a combination of factors, including population growth, overuse, pollution, and constant withdrawals [22]. These factors have considerably diminished the global availability of water [22]. Moreover, the consequences of global climate change, such as polar ice melting, rising sea levels, and natural disasters, have directly impacted the timing, availability, and variability of water supply and demand [22]. Consequently, the strain on water resources has intensified.

The COVID-19 pandemic has highlighted the critical need for sufficient water access for consumption, food production, frequent hygiene, improved sanitation, water quality, and wastewater treatment to safeguard health and safety [23]. Water scarcity can lead to water crises that adversely affect sanitary conditions, food production, and poverty levels [23]. Over the centuries, the multifaceted utilization of water has resulted in significant degradation and pollution, compromising the availability of water on our planet [24]. In addition, inadequate water management, challenges in economic and social development, and environmental complexities further exacerbate the water situation, increasing uncertainty for the future [24]. Moreover, water stress, defined as the proportion of freshwater withdrawn in relation to the total renewable freshwater resources exceeding a threshold of 25% [25], has risen by more than 2% in certain sub-regions with high or very high levels, particularly in North Africa, Central Asia, and West Asia [25]. Thus, water scarcity is an escalating concern for regions and

countries worldwide, necessitating appropriate governance and innovative technologies to effectively address these challenges [25].

Brazil has an extensive hydrographic network and significant freshwater reserves, although their distribution across the country is uneven [26–28]. Despite possessing nearly 13% of the world's freshwater resources, the country has long grappled with water security issues [26,27]. The perception of abundance has led to unrestricted water usage as the country developed its resource-based economy [29,30]. This has placed immense pressure on an urbanized nation with rapidly growing cities and income disparities [31,32]. According to Leitão and McAllister [30], many cities in Brazil have struggled to provide adequate and high-quality water supplies to their populations, as well as effective wastewater treatment. The country has faced various water management challenges over the past few decades, including dealing with powerful vested interests in sectors like hydroelectricity, economic fluctuations, and clientelism within the public bureaucracy [33]. Additionally, the uneven distribution of freshwater resources across the country further complicates the situation [29]. Population growth, increased water demand, changes in rainfall patterns, and inadequate water management have often resulted in water scarcity, shortages, and crises that affect water supply systems and socioeconomic development disparities in different parts of the country, particularly in urban areas, agricultural regions, and hydrographic basins used for power generation [30]. The insecurity of water access in medium and large Brazilian cities has been on the rise, generating vulnerabilities and risks in water supply systems that impact society as a whole [29]. For example, the city of Curitiba in the southern region experienced water scarcity and rationing in 2006 due to inadequate resource management, population growth, and low rainfall [34]. Similar water scarcity problems have occurred in the southeast region, particularly in Sao Paulo, where a severe drought affected the main water catchment area, causing significant impacts on the region's social, economic, and environmental sectors [35,36]. The mid-west region, including Brasilia, the Federal District, also faced a water crisis due to low rainfall, resulting in water rationing and impacting various sectors [37].

To address the water scarcity challenges in Brazil, the local government and water companies have implemented new technologies and innovative solutions aimed at improving water management and increasing water supply. One notable example is the establishment of the ETA Norte water treatment plant in Brasilia in 2017, which indirectly utilizes treated wastewater to enhance the local water supply system and alleviate the impacts of water scarcity [38]. The practice of reusing treated wastewater, both for non-potable and potable purposes, has emerged as a strategy to mitigate the effects of water scarcity and has been extensively studied and implemented globally, including in Brazil. It finds applications in agricultural irrigation, landscape irrigation, industrial supply, and aquifer recharge [39].

In addition to water reuse, other solutions employed to combat water scarcity encompass surface water transfer between basins and seawater desalination. These approaches have been successfully utilized in various countries worldwide, including Mediterranean nations such as Spain, Malta, Cyprus, France, Italy, Greece, Morocco, Algeria, Egypt, Turkey, and Israel, as well as other arid regions like Saudi Arabia, United Arab Emirates, Qatar, Australia, United States, Curacao, Mexico, Cape Verde, and South Africa [40–42].

In the European context, water availability challenges are also prevalent, particularly in the southern region of Europe. Water scarcity and droughts have emerged as significant issues, which are expected to be exacerbated by the impacts of climate change. Already, a considerable portion of the European population has been affected by water scarcity, posing a significant risk to the socioeconomic development in the region [43–46]. The increasing water scarcity and droughts across the European Union directly impact both citizens and economic sectors reliant on water, including agriculture, tourism, industry, power generation, and transport. Presently, approximately 11% of the European population and 17% of its territory have experienced water scarcity [44–46]. The consequences of water scarcity and droughts extend beyond water management and have wide-ranging impacts on natural resources,

biodiversity, water quality, and the risk of forest fires and soil degradation. These challenges directly affect the lives of citizens and various sectors of the economy.

Like Brazil, certain regions in Europe heavily rely on water availability for hydroelectric power generation [47]. Studies indicate a substantial increase in the number of areas affected by drought and the population impacted in Europe, with a rise of approximately 20% between 1976 and 2006. The Mediterranean region has witnessed severe drought events, with rainfall levels dropping to only 40% of the average during the period of 2011–2012 [48].

In this context, Southern Europe faces pressing water scarcity issues due to a combination of unstable climatic conditions, recurring droughts (especially in the Mediterranean basin), and increased water usage in recent decades. Many countries in the region have recognized the significance of water scarcity and have prioritized it on their political agendas [49]. For example, Spain and Portugal face challenges stemming from the irregular distribution of water resources in terms of timing and geography, resulting in significant impacts on water availability and scarcity. The Iberian Peninsula experiences more severe temporal irregularities compared to other parts of Europe, with seasonal variations in river volumes and substantial differences between wet and dry years. The misalignment of rainfall timing and water demands for irrigation and population supply further exacerbates the situation [50,51].

In Spain, unequal regional distribution of water resources in the southeast region of the Iberian Peninsula has led to serious deficits, occasional or structural, with irrigation remaining one of the primary water uses. Water scarcity has been a long-standing source of social controversy in the region, influenced by both climatic conditions and increased water usage [52,53]. Portugal shares similar conditions with Spain, particularly in terms of facing the impacts of drought, especially in its southern regions, due to its Mediterranean climate, landscape, and culture [54]. The irregular distribution of water resources, both in terms of timing and geography, significantly affects water availability in both countries.

As a result, cooperation between Portugal and Spain has been recommended to facilitate joint research addressing various aspects of water-related issues, including the impacts of climate change, water scarcity, water crises, and the development of integrated management policies that promote efficient water usage across different sectors [55]. By collaborating, both countries can leverage their shared watersheds and similarities to gain a comprehensive understanding of Iberian water challenges and develop effective strategies to mitigate them.

According to Table 1, in Portugal, there is a notable focus on investments in renewable energy sources like wind, solar, and hydroelectric power. The country has set ambitious targets to increase the share of renewables in its energy mix, aiming for carbon neutrality by 2050. Similarly, Brazil places a strong emphasis on expanding its renewable energy sources, with hydroelectric power already playing a significant role. Additionally, Brazil's investments extend to wind, solar, and biomass energy.

Portugal prioritizes energy efficiency enhancement across various sectors, including buildings, transportation, and industries. The aim is to reduce overall energy consumption and consequent greenhouse gas emissions. In contrast, Brazil is a global leader in biofuel production, particularly ethanol from sugarcane, which contributes to reducing carbon emissions from transportation.

Portugal has adopted policies that put a price on carbon emissions, aiming to incentivize businesses and industries to reduce their carbon footprint. Brazil's approach includes promoting sustainable agricultural practices, such as no-till farming and agroforestry, to mitigate the agriculture sector's carbon emissions.

Table 1. Climate change mitigation efforts.

Strategies	Portugal	Brazil
Renewable energy	Investments in renewable energy sources, particularly wind, solar, and hydroelectric power. Ambitious targets for increasing the share of renewables in its energy mix, aiming to achieve carbon neutrality by 2050.	The country has a strong commitment to expanding its renewable energy sources, particularly hydroelectric power, which already plays a significant role in Brazil's energy mix. Investments in wind, solar, and biomass energy have also been increasing.
Energy efficiency	Efforts to enhance energy efficiency in various sectors, including buildings, transportation, and industries, have been a priority. Energy efficiency measures help reduce overall energy consumption and subsequently lower greenhouse gas emissions.	Brazil is a global leader in biofuel production, primarily ethanol from sugarcane. The use of biofuels for transportation helps reduce carbon emissions from fossil fuels.
Carbon pricing and low-carbon agriculture	Policies to put a price on carbon emissions, which can incentivize businesses and industries to reduce their carbon footprint. This can be achieved through mechanisms like carbon taxes or emissions trading systems.	Brazil's agriculture sector is a major contributor to emissions. Initiatives to promote sustainable agricultural practices, such as no-till farming and agroforestry, aim to reduce the sector's carbon footprint
Reforestation and afforestation	Afforestation and reforestation projects have been undertaken to increase the country's forest cover and sequester carbon dioxide from the atmosphere. Healthy forests play a crucial role in mitigating climate change by acting as carbon sinks.	Brazil's Amazon rainforest is a critical carbon sink, and efforts to reduce deforestation have been a significant focus. Government policies, satellite monitoring, and enforcement have been employed to combat illegal logging and land conversion. In addition to curbing deforestation, Brazil has been involved in reforestation and restoration efforts, including through the "Brazilian Low-Carbon Agriculture" program.
Sustainable transportation	Promotion of sustainable transportation options, including electric vehicles (EVs) and improving public transportation infrastructure. This helps reduce emissions from the transportation sector, a significant contributor to greenhouse gas emissions.	Brazil is working to improve public transportation infrastructure and promote cleaner modes of transportation, including electric vehicles
Climate policy and legislation	Climate policies and legislation aimed at reducing emissions and promoting sustainability. These policies outline targets, strategies, and measures to address climate change at the national level.	The country has implemented various policies and regulations to address climate change, including the National Policy on Climate Change and its commitment to the Paris Agreement.
International cooperation	Portugal has actively participated in international climate negotiations and agreements, such as the Paris Agreement. This demonstrates the country's commitment to global efforts to combat climate change	Brazil has participated in global climate negotiations and has been involved in international agreements like the Paris Agreement.
Research and innovation	Research institutions and organizations in Portugal have been engaged in developing innovative solutions for climate change mitigation and adaptation. This includes advancements in renewable energy technologies and sustainable agriculture practices.	Research institutions and organizations in Brazil have been conducting studies and developing technologies to advance climate change mitigation efforts, including sustainable land use practices and renewable energy innovations

Source: Authors' analysis based on https://climateknowledgeportal.worldbank.org/country/portugal, accessed on 1 July 2023.

Both countries recognize the significance of reforestation and afforestation in carbon sequestration and climate change mitigation. Portugal undertakes afforestation and reforestation projects to increase forest cover. Similarly, Brazil focuses on preserving its Amazon rainforest, employing policies, satellite monitoring, and enforcement to combat illegal logging and promote reforestation and restoration.

Portugal actively promotes sustainable transportation options, including electric vehicles (EVs) and improvements in public transportation infrastructure. Similarly, Brazil is working on enhancing public transportation infrastructure and encouraging cleaner modes of transportation, including electric vehicles. Both Portugal and Brazil demonstrate their commitment to addressing climate change through comprehensive climate policies and legislation. These frameworks outline specific targets, strategies, and measures for tackling climate challenges on a national scale. Moreover, both Portugal and Brazil actively participate in global climate negotiations and agreements, indicating their dedication to international collaborative efforts for combating climate change.

Research institutions and organizations in both countries are engaged in developing innovative solutions for climate change mitigation and adaptation. Portugal's advancements include renewable energy technologies and sustainable agriculture practices, while Brazil focuses on technologies for sustainable land use and renewable energy innovations.

In summary, Portugal and Brazil each adopt a range of strategies tailored to their specific circumstances in the pursuit of climate change mitigation. These strategies encompass renewable energy, energy efficiency, carbon pricing, reforestation, sustainable transportation, climate policies, international cooperation, and research and innovation.

4. Water Management: Complexities and Collaborative Strategies

There is typically an overlap between interests, powers, and norms surrounding policies and strategies for managing water resources and wastewater sanitation. These complexities are prone to hindering public managers from implementing effective policies that might benefit society and the environment. Currently, water management is no longer restrained to political and administrative borders; rather, it has expanded to regional and continental limits.

In Brazil, the National Water Resources Policy was established by Federal Law No. 9433 in 1997. This progressive legislation provides the foundation for proper water resource management in the country. It aims to ensure water security for society's needs and sustainable economic activities. Similarly, the National Basic Sanitation Policy, instituted by Federal Law No. 11445 in 2007 and modified by the New Basic Sanitation Framework (Law No. 14026), aims to provide 99% of the population with access to clean drinking water and 90% with sewage treatment and collection by 31 December 2033.

Currently, a significant portion of the population lacks access to treated water and sewage collection services. Efficient sanitation policies are crucial for promoting sewage treatment and preventing environmental contamination and public health issues. Properly treated sewage also plays a vital role in planning and sustainably managing water resources, including their reuse for non-potable purposes. This technology can greatly contribute to addressing and mitigating the impacts of droughts, shortages, and water crises.

In countries with high urbanization rates like Brazil and several EU nations, the relationship between urban policies and water resources is particularly important. Effective cooperation and integration between these two institutional systems are crucial, especially in heavily urbanized areas where land use and occupation directly affect the sustainability of water systems. Insufficient and ineffective environmental sanitation policies often lead to the degradation of water resources. Many developing countries face this issue, with a lack of access to clean water and inadequate sewage networks. These factors contribute to a diminished quality of life for the population.

Water resources in the European Union also face increasing pressure due to the growing demand for good-quality water for various uses. To protect and improve water quality, the Water Framework Directive (WFD) was introduced in the EU. It established a community

framework for water policy, adopting an integrated approach to water protection, ecological assessment of water quality, integrated planning at the river basin level, pollution elimination strategies, financial instruments, information dissemination, public participation, and a comprehensive legal framework for water. Portugal transposed the WFD into its legal system through the Water Law in 2005. The law provides a framework for managing surface water, including inland, transitional, and coastal waters, as well as groundwater. The country also introduced a new strategy for the water supply and wastewater sanitation sector, which succeeded the strategic plan for water supply and wastewater sanitation. This strategy focuses on resource valorization, efficient resource use, risk prevention, climate change adaptation, protection of the environment, and transitioning to a low-carbon economy.

Although Portugal has made positive progress in the water supply and wastewater sanitation sector, there are still concerns regarding the achievement of the established targets. The next plan, PENSAARP 2030 (2021–2030), is currently being finalized and will guide new policies for the urban water cycle and its integration with other sectoral policies. Additionally, the National Program for the Efficient Use of Water (PNUEA) aims to promote efficient water use in urban, agricultural, and industrial sectors to minimize water scarcity risks and improve environmental conditions without compromising vital needs and quality of life. Comparative studies between the water management policies of the European Union and Brazil would be essential to explore how Brazil, Portugal, and other European countries can learn from each other and draw examples and lessons. These studies would help in implementing water management practices that ensure water security for societies while simultaneously protecting and sustaining the environment. By analyzing the strengths and weaknesses of each system, countries can identify areas for improvement and adopt effective strategies that align with their specific contexts. Such comparative studies would contribute to the development of robust and adaptable water management policies that address the challenges posed by water resources and wastewater sanitation.

Water crises can have significant effects on cultures around Europe, which can vary depending on the severity and duration of the water crisis, as well as the specific cultural and geographical contexts. Some potential impacts include:

Agriculture and food security: Water scarcity can disrupt agricultural practices, affecting crop yields and food production. Traditional farming practices and cultural diets may need to adapt or change, leading to shifts in culinary traditions and food availability.

Tourism and recreation: Water-related tourism, such as river cruises, beach vacations, and water sports, may be impacted by reduced water availability or deteriorating water quality. This can affect both local economies and the ways in which people engage with their leisure time.

Water-based industries: Industries such as fishing, shipping, and manufacturing that rely on water resources can face challenges during water crises. Disruptions in these sectors can have economic and cultural repercussions for communities that have been traditionally dependent on such industries.

Social dynamics: Water scarcity can lead to increased competition for water resources, potentially exacerbating existing social tensions and inequalities. This can impact community cohesion and relationships.

Migration and urbanization: In more severe cases, prolonged water scarcity could lead to population movements as people seek more water-secure areas. This can result in changes in demographics and cultural dynamics both in affected and receiving areas.

To summarize, addressing water scarcity often requires a combination of sustainable water management, cultural adaptation, and social resilience measures.

5. Socioeconomic Factors, Cultural Factors, and Digital Transformation

Socio-economic and cultural factors play a crucial role in shaping the effectiveness of water management strategies. These factors influence people's behaviors, attitudes, and perceptions towards water resources, as well as their access to water and sanitation

services. Understanding and addressing these socio-economic and cultural considerations are essential for developing sustainable and inclusive water management policies [56].

Using data from the United Nations on Sustainable Development Goal 6 [57], we explore some of the potential socio-economic and cultural factors that could impact the effectiveness of water management strategies in Brazil and Portugal. Socio-economic inequalities can affect access to clean water and sanitation services. In both Brazil and Europe, marginalized communities, including low-income households and informal settlements, often face challenges in accessing reliable water supplies and proper sanitation facilities [58]. Addressing these disparities requires targeted policies and interventions that prioritize equitable distribution of water resources and infrastructure development. Figure 1 shows some water management indicators for 2020.

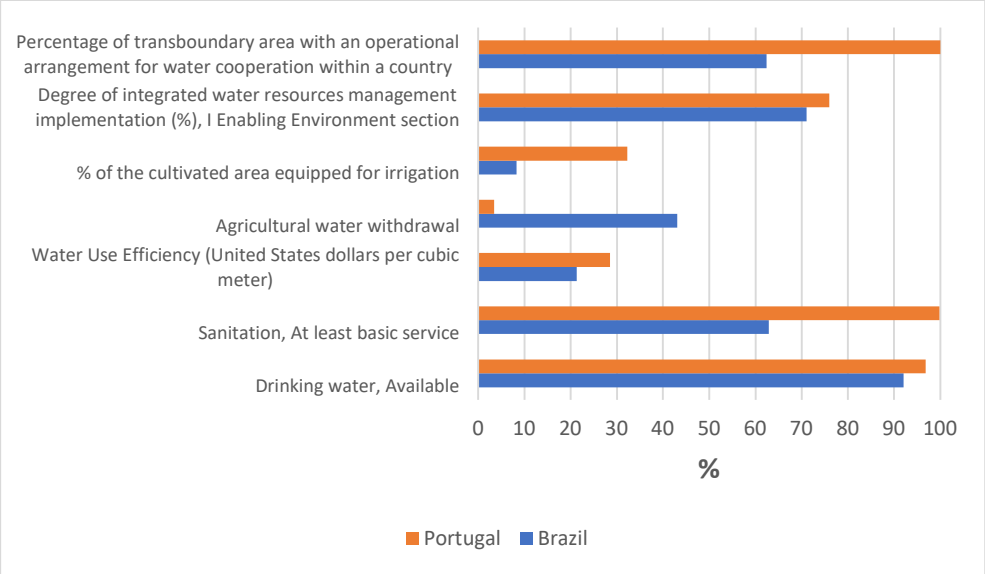

Figure 1. Water management indicators, 2020. Notes: Values for agricultural water withdrawal, and the % of the cultivated area equipped for irrigation, refer to 2019. Source: United Nations (https://www.sdg6data.org, accessed on 1 July 2023) [19].

Portugal has a significantly higher percentage of drinking water available (96.79%), and its sanitation services cover a higher percentage of the population with at least basic services (99.8%). In contrast, Brazil has a lower percentage of drinking water available (92.06%) and basic sanitation services (62.9%).

Cultural beliefs, traditions, and practices can influence water management behaviors. For example, in some regions, there may be cultural norms around water usage, such as excessive consumption or inefficient irrigation practices. Understanding and engaging with local cultures and traditions are crucial for promoting sustainable water practices and behavior change. Public awareness campaigns and education programs can help foster a culture of water conservation and responsible water use.

Regarding water use efficiency, both countries have relatively low values, but Portugal has a slightly higher value (28.49 USD per cubic meter) than Brazil (21.29 USD per cubic meter).

Agriculture is a significant consumer of water resources in both Brazil and Europe. The type of crops cultivated, irrigation techniques employed, and agricultural policies can significantly impact water availability and quality. Sustainable agricultural practices, such as efficient irrigation systems, crop rotation, and agroecology, can minimize water consumption and reduce pollution. However, the adoption of such practices may require policy incentives, technical support, and farmer education programs. Portugal also has a much lower agricultural water withdrawal rate (3.42) compared to Brazil (43.03).

Industrial activities, including manufacturing and energy production, have a substantial water footprint. The nature of industries, their water use efficiency, and treatment of

wastewater can influence overall water management effectiveness. Implementing stringent regulations, promoting water-efficient technologies, and encouraging industrial sectors to adopt sustainable water practices are critical for minimizing the negative environmental impacts of industrial water use. Rapid urbanization in Brazil and Europe presents unique challenges for water management. Urban expansion and changes in land use patterns can lead to increased runoff, decreased infiltration, and the loss of natural water storage areas. Integrated urban planning approaches that consider water-sensitive designs, green infrastructure, and sustainable land use practices can help mitigate the negative impacts of urbanization on water resources.

Portugal has more of its cultivated area equipped for irrigation (32.26%) compared to Brazil (8.33%). This indicates that Portugal is better equipped to manage water resources for agricultural purposes, which could lead to higher yields and overall better agricultural performance. As for public participation and governance, effective water management relies on the active participation of communities, civil society organizations, and stakeholders. The level of public awareness, engagement, and trust in water management institutions can influence the implementation and success of policies. Establishing mechanisms for public participation, transparency, and accountability can foster inclusive decision-making processes and ensure that water management strategies address the needs and concerns of all stakeholders. Concerning the management of water resources, Portugal has a higher degree of integrated water resource management implementation (76%) compared to Brazil (71%).

Climate change poses significant challenges to water resources in both Brazil and Europe. Changing precipitation patterns, increased frequency of extreme weather events, and rising temperatures impact water availability, quality, and infrastructure. Adaptive water management strategies that consider climate change projections, prioritize resilience, and promote the use of climate-resilient technologies are essential for ensuring long-term sustainability. Effective collaboration on transboundary water resources is essential for addressing regional security challenges and facilitating climate change adaptation.

Additionally, Portugal has a higher percentage of transboundary areas with operational arrangements for water cooperation within the country (100%) compared to Brazil (62.36%). Overall, Portugal performs better than Brazil in several aspects related to water management, sanitation, and agricultural management. Addressing the socio-economic and cultural factors that influence water management effectiveness requires a multi-dimensional and inclusive approach. Policymakers, water managers, and stakeholders must collaborate to develop context-specific strategies that consider the socio-economic realities, cultural practices, and unique challenges faced by different regions and communities. By integrating socio-economic and cultural considerations into water management policies, Brazil and Europe can foster sustainable practices, ensure equitable access to water resources, and protect the environment for future generations.

Digital transformation in water management refers to the integration of digital technologies, data analytics, and smart solutions to optimize the use, distribution, and conservation of water resources. This transformation aims to enable real-time monitoring, predictive analytics, and efficient decision-making processes, ultimately leading to better water resource management. Portugal has been at the forefront of digital transformation in water management, embracing advanced technologies to address its unique water challenges. One notable initiative is the adoption of smart water meters and sensors that collect real-time data on water consumption and quality [59]. These data-driven insights allow water utilities to detect leaks, reduce water losses, and optimize water distribution networks [60]. Furthermore, Portugal has invested in geographic information systems (GIS) to map water resources, infrastructure, and potential risks [61]. This enables policymakers to make informed decisions based on spatial data and better understand the water dynamics across the country. Moreover, Portugal has developed innovative water management platforms that facilitate data sharing and collaboration among stakeholders [62]. These platforms encourage public participation and allow citizens to contribute valuable information, leading to more inclusive and transparent water governance. Despite its advancements,

Portugal faces challenges in fully embracing digital transformation in water management. These include issues related to data privacy and cybersecurity, the cost of implementing new technologies, and ensuring equitable access to digital solutions across all regions and communities [63].

Brazil, too, has recognized the potential of digital transformation in water management. One prominent initiative is the use of remote sensing and satellite technology to monitor water resources, particularly in remote and hard-to-reach areas [64]. These technologies help assess water availability, track changes in water bodies, and support drought prediction and management. Additionally, Brazil has been investing in real-time data monitoring systems for urban water supply and wastewater treatment [65]. This approach enables water utilities to optimize operations, improve water quality, and respond promptly to any water-related issues. Moreover, Brazil has integrated advanced data analytics and artificial intelligence (AI) into its water management practices. These technologies enable predictive modeling, helping policymakers anticipate future water demands and plan accordingly. Despite its progress, Brazil faces challenges in implementing digital water management solutions effectively. Limited funding and infrastructure in some regions hinder the adoption of new technologies. Additionally, ensuring data interoperability and building capacity among water management professionals remain essential hurdles to overcome [66].

Both Portugal and Brazil can expect numerous benefits from embracing digital transformation in water management. Some of these include:

Improved water efficiency: Real-time data monitoring and analytics help identify inefficiencies and water losses, leading to better water conservation practices.

Enhanced decision-making: Data-driven insights enable policymakers to make informed and proactive decisions in managing water resources effectively.

Sustainable water management: Digital transformation promotes the adoption of sustainable practices, optimizing water use and reducing the environmental impact.

Climate Resilience: Digital tools help anticipate climate-related challenges and implement adaptive strategies to mitigate the effects of climate change on water resources.

Digital transformation presents a significant opportunity for Portugal and Brazil to revolutionize their water management practices. Embracing advanced technologies, data analytics, and smart solutions can lead to more efficient and sustainable water resource management. However, both countries must address the challenges posed by data privacy, infrastructure limitations, and funding to fully harness the potential of digital transformation in water management. By fostering collaboration and knowledge-sharing, Portugal and Brazil can pave the way for a water-secure future and contribute to global efforts in sustainable water resource management.

Table 2 showcases how different scenarios influence water management strategies in Portugal and Brazil, taking into account irrigation needs, efficiency measures, irrigation technologies, and water availability. It underscores the diverse approaches necessary to address each country's specific challenges and opportunities in water resource management.

Socio-economic and cultural considerations are critical in shaping the effectiveness of water management strategies. These factors influence behaviors, attitudes, and access to water and sanitation services. Addressing these factors is essential for developing sustainable and inclusive water management policies.

Digital transformation offers immense potential for optimizing water management. Both Portugal and Brazil have embraced advanced technologies to improve water efficiency, quality, and availability. While Portugal leads in adopting smart solutions and data-driven insights, Brazil has also harnessed remote sensing and AI for better water resource monitoring and management.

Table 2. Scenarios considering different factors related to irrigation requirement, water use efficiency, irrigation efficiency, and water availability in both Portugal and Brazil.

Scenarios	Water Management Factors	Portugal	Brazil
1. Water stress and inefficient practices	Dominant irrigation requirement	Moderate due to various agricultural activities.	High in certain agricultural regions.
	Water use efficiency	Low, with traditional irrigation methods prevailing.	Low, with significant water losses due to inefficient practices.
	Irrigation efficiency	Low, as outdated irrigation systems are common.	Low, with a mix of technologies.
	Water availability	Relatively moderate, but susceptible to climate variability.	Varies widely, with some regions facing severe water stress.
2. Sustainable water practices	Dominant irrigation requirement	Moderate, primarily for vineyards and orchards.	Varied based on regions and crops.
	Water use efficiency	Moderate as a result of adopting efficient irrigation techniques.	Moderate to high, due to efforts in adopting water-saving practices.
	Irrigation efficiency	Moderate, with a shift towards modern systems.	Varied, with a transition towards more efficient systems.
	Water availability	Adequate with proactive water management measures.	Moderate to high, depending on the region, with better water management.
3. Climate resilience and advanced technologies	Dominant irrigation requirement	Moderate, with adaptive strategies.	Varied, with a focus on efficient water use.
	Water use efficiency	High, due to advanced irrigation techniques.	High, with comprehensive water-saving initiatives.
	Irrigation efficiency	High, with the integration of smart irrigation systems.	High, utilizing cutting-edge technologies.
	Water availability	Managed effectively with climate-resilient infrastructure.	Managed sustainably, even in water-stressed regions, through innovative practices.

Source: Own analysis based on references [19,20,56–66].

Both countries face water stress due to factors such as climate variability and inefficient practices. Scenario 3, emphasizing climate resilience and advanced technologies, emerges as a robust strategy. This scenario harnesses high water use efficiency, modern irrigation systems, and smart technologies to manage water effectively under changing climatic conditions.

Equitable access to water resources is crucial, particularly for marginalized communities. Scenarios 2 and 3 prioritize this aspect, aiming for better water management across different regions and sectors. Collaboration among stakeholders, transparent governance, and inclusive decision-making processes are essential for achieving these goals.

According to Table 3, Scenario 3 emerges as the most efficient and sustainable water use strategy for addressing water stress and inefficiencies, while also demonstrating climate resilience. Socio-economic and cultural factors play pivotal roles necessitating effective policies, and Scenario 3's comprehensive digital transformation enhances water management. Sustainable agriculture and improved water quality are promoted in all scenarios. Equitable access, collaboration, and governance are emphasized in Scenarios 2 and 3, and Scenario 3 stands out for its potential for ensuring long-term water resource sustainability and environmental protection.

Table 3. Comparison of scenarios.

Efficiency and Sustainability	Scenario 3 leads to the most efficient and sustainable water use in both countries, addressing the challenges of water stress and wasteful practices.
Climate Resilience	Scenario 3 is most effective in preparing for climate change impacts, ensuring water availability even under changing conditions.
Cultural and Socioeconomic Impacts	In all scenarios, socio-economic and cultural factors play a vital role. Effective policies and educational campaigns are crucial for behavior change.
Digital Transformation	Scenario 3 leverages digital transformation for real-time monitoring, predictive analytics, and smart solutions, enhancing overall water management effectiveness.
Agricultural Impact	Scenario 3 promotes sustainable agricultural practices, minimizing water consumption while maintaining productivity.
Water Quality	All scenarios can contribute to improved water quality through efficient water use and pollution control measures.
Equitable Access	Scenarios 2 and 3 emphasize equitable access to water resources, considering marginalized communities
Collaboration and Governance	Scenario 3 encourages stakeholder engagement and transparent governance, fostering inclusive decision-making processes.
Long-Term Sustainability	Scenario 3 is most likely to ensure long-term water resource sustainability and environmental protection.

Source: Own analysis.

6. SWOT Analysis and Discussion

The paper provides an analysis of the water management policies and challenges in Brazil, Portugal, and other European Union countries. We propose the following SWOT analysis for water resource management in Brazil and Portugal:

Strengths:

1. Strong legal frameworks: Both Brazil and Portugal have established legal frameworks for water resource management, incorporating policies and regulations to protect and improve water quality.
2. Integrated approach: Both countries have adopted an integrated approach to water management, considering ecological assessment, pollution elimination strategies, financial instruments, and public participation.
3. Strategies for efficient resource use: Portugal has implemented a strategy for water supply and wastewater sanitation, focusing on resource valorization and efficient resource use. Brazil has also recognized the importance of efficient water use through the National Program for the Efficient Use of Water (PNUEA).
4. Comparative studies: Brazil, Portugal, and other European countries can learn from each other through comparative studies, facilitating the exchange of examples and lessons in water management practices.

Weaknesses:

1. Achievement of targets: Portugal has made progress in the water supply and wastewater sanitation sector, but there are concerns about achieving established targets. Continuous efforts are required to ensure the effective implementation of policies and meet desired outcomes.
2. Socio-economic disparities: Both countries face socio-economic disparities, resulting in marginalized communities having difficulties accessing reliable water supply and sanitation facilities. Targeted policies and interventions are needed to address these disparities and ensure equitable distribution of water resources.

3. Cultural practices and perceptions: Cultural norms and practices may influence water management behaviors, leading to excessive consumption or inefficient irrigation practices. Promoting cultural change and fostering water conservation practices require public awareness campaigns and education programs.
4. Agricultural water use: Agriculture is a significant consumer of water resources in both countries. Encouraging the adoption of sustainable agricultural practices, such as efficient irrigation systems and agroecology, may require policy incentives, technical support, and farmer education programs.

Opportunities:

1. Knowledge sharing and collaboration through comparative studies between Brazil, Portugal, and European countries will facilitate the development of robust and adaptable water management policies.
2. Enhancing public participation, transparency, and accountability will improve the effectiveness of water management strategies. Engaging communities and stakeholders in decision-making processes leads to more inclusive and sustainable water governance.
3. Emphasizing adaptive water management strategies will help to address climate change challenges, considering projections and promoting resilience for long-term sustainability.
4. Exploring the potential of nature-based solutions for water management is essential.
5. Promoting water recycling and reuse to optimize water resources and reduce wastage.
6. Integration of smart water technologies for real-time monitoring and data-driven decision-making will enable efficient and informed management practices.

Threats:

1. Water scarcity risks: Increasing water demand and climate change can pose threats to water availability and quality in both Brazil and Portugal. Developing strategies to minimize water scarcity risks and protect water resources is crucial.
2. Industrial water use: Industrial activities have a significant water footprint and can impact water availability and quality. Implementing regulations and promoting sustainable practices in industrial water use are necessary for mitigating negative environmental impacts.
3. Urbanization and land use: Rapid urbanization can lead to challenges in water management such as increased runoff and decreased natural water storage areas. Integrated urban planning approaches that consider water-sensitive designs and sustainable land use practices are essential to address these challenges.

The results of the analysis confirm the hypotheses proposed in this study, as strong legal frameworks, socio-economic disparities, cultural practices, perceptions, agricultural water use, knowledge sharing, collaboration, public participation, governance, climate change resilience, water scarcity risks, industrial water use, urbanization, and land use were identified as significant factors influencing water management strategies in Brazil and Portugal. By comparing these policies, this article offers insights into potential areas for improvement and best practices that can be adopted across regions. Also, we highlight the importance of integrated water management approaches, considering the interconnections between urban policies, water resources, and environmental sustainability. This perspective can guide policymakers and public managers in developing strategies that effectively address the complex challenges of water management. This research emphasizes the significance of wastewater treatment and the reuse of treated wastewater as a sustainable solution for mitigating the impacts of droughts, water scarcity, and water crises. Its findings contribute to ongoing discussions on water conservation and the efficient use of resources. By exploring the limitations and factors influencing water management, this paper encourages further research and discussion on this topic. It provides a foundation for future studies that can delve deeper into specific aspects or regions, considering additional variables and perspectives. We aim to contribute to the global understanding of water management challenges, particularly in the context of accelerated urbanization and population growth. Our findings can inform policy development and decision-making processes in various

countries facing similar issues. In addition, we attempt to raise awareness about the need for collaborative approaches, inter-institutional cooperation, and public participation in water management. We emphasize the importance of addressing not only technical and legal aspects but also societal attitudes and cultural factors in achieving effective water governance. This research identifies gaps in water management policies and practices, emphasizing the necessity of investments in science, technology, and infrastructure. This insight can guide policymakers in allocating resources and implementing measures that support sustainable water management. Furthermore, this research contributes to the broader discourse on water security, environmental sustainability, and the integration of water resource management at regional and global scales, providing a basis for comparative studies and knowledge sharing between countries to foster continuous improvement in water management practices.

Policy Implications:

Socio-economic and cultural sensitivity: Water management policies should consider the socio-economic and cultural context of different regions. Tailored strategies are needed to ensure equitable access and participation, addressing the challenges faced by marginalized communities.

Digital transformation integration: Policymakers should invest in integrating digital technologies, data analytics, and smart solutions into water management practices. This includes real-time monitoring, predictive analytics, and the adoption of smart systems to enhance decision-making processes and improve overall water efficiency.

Climate-resilient strategies: Prioritizing climate resilience and adopting advanced technologies can significantly enhance water management strategies. Policies should encourage the use of climate-resilient infrastructure, smart irrigation systems, and predictive modeling to ensure consistent water availability in changing climatic conditions.

Equitable access and collaboration: Policies should focus on ensuring equitable access to water resources, particularly for vulnerable communities. Stakeholder engagement, public participation, and transparent governance mechanisms are essential for effective water resource management.

Long-term sustainability: Strategies like Scenario 3, which emphasize sustainability, climate resilience, and advanced technologies, should be prioritized for their potential to ensure long-term water resource sustainability, environmental protection, and improved quality of life.

Capacity building and funding: Both countries should invest in capacity building for professionals in water management and secure funding to implement digital transformation and advanced technologies effectively. Overcoming challenges related to infrastructure, data interoperability, and funding is crucial for successful implementation.

In conclusion, effective water management strategies must account for socio-economic and cultural factors, embrace digital transformation, prioritize climate resilience, ensure equitable access, promote collaboration, and work towards long-term sustainability. By aligning policies with these considerations, Portugal and Brazil can make substantial progress towards managing their water resources efficiently and sustainably.

Policymakers should prioritize the adoption of strategies similar to Scenario 3, which combine efficiency and sustainability to address water stress and inefficiencies. Scenario 3's success in climate resilience should guide policies that invest in adaptive measures and technologies to ensure consistent water availability in the face of changing climate patterns. Acknowledging the significance of socio-economic and cultural factors, policymakers should design and implement effective policies and campaigns that encourage responsible water usage across different communities. Emulating Scenario 3's emphasis on digital transformation can enhance overall water management effectiveness through real-time monitoring, analytics, and smart solutions.

Policies that encourage sustainable agricultural practices, as demonstrated in Scenario 3, should be promoted to minimize water consumption while maintaining agricultural productivity. Taking inspiration from Scenarios 2 and 3, policymakers should

design strategies that prioritize equitable access to water resources, ensuring the inclusion of marginalized communities. Scenario 3's emphasis on collaboration and governance should guide policies that foster stakeholder engagement, transparency, and inclusive decision-making processes in water management. Policies should align with Scenario 3's comprehensive approach to ensure the long-term sustainability of water resources and environmental protection, addressing emerging challenges proactively.

However, this analysis presents limitations that include regional focus (Brazil and Portugal), reliance on the existing literature, data availability, the potential for a more holistic approach, and the snapshot nature of the analysis. To address these limitations, future studies could consider a broader geographic scope and incorporate more primary data collection, allowing for a more comprehensive and in-depth analysis of water management practices and challenges in different regions.

7. Conclusions

The analysis conducted in this study confirms the validity of the formulated hypotheses. Strong legal frameworks (H1) indeed play a positive role in influencing effective and sustainable water management strategies. Socio-economic disparities, cultural practices, and public participation (H2) have been identified as significant factors impacting water management strategies, leading to challenges in equitable access, distribution, and conservation of water resources. Agricultural and industrial water use practices (H3) are substantiated as substantial influencers of water management strategies, affecting water consumption, sustainability, and environmental impacts. Additionally, the findings support the premise that climate change resilience, water scarcity risks, and urbanization (H4) significantly shape water management strategies, highlighting the need for proactive measures, long-term planning, and sustainable land use practices to mitigate negative effects on water resources. These outcomes collectively underscore the interconnected nature of socio-economic, cultural, technological, and environmental factors in shaping effective water resource management strategies.

This analysis has provided a comprehensive exploration of water resource management strategies in Brazil and Portugal, highlighting their strengths, weaknesses, opportunities, and threats. By dissecting various facets of water governance, including legal frameworks, socio-economic influences, cultural factors, and digital integration, a nuanced comprehension of the multifaceted water challenges has been elucidated.

The strengths identified in both nations, such as robust legal structures, integrated approaches, and initiatives for promoting efficient water use, lay a robust groundwork for tackling water-related complexities. However, the weaknesses, encompassing target achievement disparities, socio-economic inequalities, and cultural behaviors impacting water practices, underscore the imperative for tailored and holistic approaches that engage diverse stakeholders. In the realm of opportunities, both countries can leverage knowledge exchange and cross-country collaboration to gain insights from each other as well as from other European counterparts. By enhancing public participation, embracing adaptive management tactics, and advocating for water recycling and reuse, Brazil and Portugal can adeptly navigate the challenges posed by climate change and escalating water demand. Nonetheless, these opportunities should be pursued with a keen awareness of the looming threats, including the risks of water scarcity due to climate change, the consequences of industrial water use, and the complexities arising from urbanization. Effectively countering these threats mandates a concerted effort towards integrating smart water technologies, promoting sustainable industrial practices, and executing well-coordinated urban planning initiatives.

The synthesis of this analysis underscores the indispensability of comprehensive and integrated approaches to water resource management. Confronting water challenges extends beyond mere technical solutions; it entails a confluence of legal, socio-economic, cultural, and technological interventions. The policy implications derived from this analysis advocate for the adoption of adaptive strategies, the cultivation of equitable access, the harnessing of digital transformation, and the prioritization of enduring sustainability.

While the focal point of this paper has been Brazil and Portugal, the insights garnered possess a broader resonance for global water management. The experiences shared between these two nations offer valuable insights for other regions grappling with akin water-related predicaments. As this trajectory progresses, further research collaborations and the implementation of visionary policies will play instrumental roles in shaping a water-secure future: a future where the predicaments of water scarcity, efficient utilization, and environmental safeguarding are adeptly tackled and addressed.

Future research endeavors could amplify the scope of this analysis to encompass a wider geographic canvas, thereby offering a more comprehensive perspective on water management across diverse contexts. Furthermore, delving into the effectiveness and feasibility of specific policy interventions in these regions could provide a deeper understanding of their real-world impacts. Moreover, examining the cross-border dynamics of water resource management and its implications for transboundary cooperation could offer valuable insights into global water security efforts. These insights underscore the intricate nature of water management and its inextricable ties to various societal facets. As we navigate an era of escalating water challenges, the holistic strategies delineated in this analysis serve as guideposts towards a sustainable and water-resilient future for Brazil, Portugal, and beyond.

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