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IMPORTANCE OF THE FRESHWATER PROGRAM AS A SUSTAINABLE DESALINATION SYSTEM FOR PRODUCTION OF DRINKING WATER IN THE SEMI-ARID REGION OF PERNAMBUCO

IMPORTÂNCIA DO PROGRAMA ÁGUA DOCE, COMO SISTEMA DE DESSALINIZAÇÃO SUSTENTÁVEL PARA PRODUÇÃO DE ÁGUA POTÁVEL NO SEMIÁRIDO PERNAMBUCANO

IMPORTANCIA DEL PROGRAMA DE AGUA DULCE COMO SISTEMA DE DESALACIÓN SOSTENIBLE PARA LA PRODUCCIÓN DE AGUA POTABLE EN LA REGIÓN SEMIÁRIDA DE PERNAMBUCO

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ABSTRACT

This article examines desalination systems in the Brazilian semi-arid region, focusing on the key pillars of management, sustainability, and social participation. The research highlights the challenges faced by rural communities with limited access to drinking water, emphasizing the environmental impacts caused by poor management of saline waste and presenting desalination as a viable and strategic alternative. Based on theoretical, regulatory, and official sources, the study proposes the requalification of these systems through democratic and environmentally responsible public policies aligned with the guidelines of the Água Doce Program (PAD) and state policies. Recommendations are provided for technical, social, and environmental improvements aimed at promoting a more efficient and inclusive management of water resources in the region.

Keywords: Drinking Water. Crystalline Basement. Desalination. Brazilian Semi-Arid. Public Management. Social Participation. Sustainability. Água Doce Program.

RESUMO

Este artigo analisa os sistemas de dessalinização no semiárido brasileiro, com foco nos eixos estruturantes da gestão, sustentabilidade e participação social. A pesquisa destaca os desafios enfrentados por comunidades rurais com acesso limitado à água potável, ressaltando os impactos ambientais provocados pela má gestão dos rejeitos salinos e apontando a dessalinização como uma alternativa viável e estratégica. Com base em referenciais teóricos, normativos e fontes oficiais, o estudo propõe a requalificação desses sistemas por meio de políticas públicas democráticas, ambientalmente responsáveis e alinhadas às diretrizes do Programa Água Doce (PAD) e às políticas estaduais. São apresentadas recomendações para o aprimoramento técnico, social e ambiental, com vistas à promoção de uma gestão mais eficiente e inclusiva dos recursos hídricos na região.

Palavras-chave: Água Potável. Embasamento Cristalino. Dessalinização. Semiárido Brasileiro. Gestão Pública. Participação Social. Sustentabilidade. Programa Água Doce.

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RESUMEN
Este artículo analiza los sistemas de desalinización en el Semiárido brasileño, centrándose en los ejes estructurales de gestión, sostenibilidad y participación social. La investigación destaca los desafíos que enfrentan las comunidades rurales con acceso limitado al agua potable, destacando los impactos ambientales causados por la mala gestión de los residuos salinos y señalando la desalinización como una alternativa viable y estratégica. Con base en marcos teóricos y regulatorios, así como en fuentes oficiales, el estudio propone la recalificación de estos sistemas mediante políticas públicas democráticas y ambientalmente responsables, alineadas con los lineamientos del Programa de Agua Dulce (PAD) y las políticas estatales. Se presentan recomendaciones para mejoras técnicas, sociales y ambientales, con el objetivo de promover una gestión más eficiente e inclusiva de los recursos hídricos en la región.

Palabras clave: Agua Potable. Base Cristalina. Desalinización. Semiárido Brasileño. Gestión Pública. Participación Social. Sostenibilidad. Programa de Agua Dulce.

1 INTRODUCTION

Although the Earth has an immense amount of water, access to clean water remains one of humanity's greatest challenges. According to the United Nations (UNESCO, 2025), more than 2 billion people live without safe access to drinking water, and about 4.4 billion do not have properly managed services, such as efficient infrastructure, continuous availability and absence of contamination.

This apparent abundance hides a harsh reality: only 0.26% of the planet's fresh water is immediately available for human consumption, concentrated in accessible rivers, lakes and aquifers. The remaining 97.5% is composed of salty or inaccessible water, such as that stored in glaciers and deep underground reservoirs (UNESCO, 2021).

Despite this limitation, the demand for drinking water is growing rapidly, driven by population growth — which by 2025 already exceeds 8.23 billion people (UNESCO, 2025) — and by economic and social development models that require high consumption of this natural resource (UNEP, 2024).

The situation is aggravated by widespread waste and contamination of water sources. In Brazil, about 40% of drinking water is lost before reaching homes, due to leaks, fraud, and infrastructure failures. On a global scale, more than 80% of wastewater is discharged without proper treatment, polluting waterways and aquifers. In addition, inefficient management of water resources and a lack of robust investments aggravate the situation, often under the connivance or impotence of governments in the face of the crisis (UNESCO, 2021).

Without significant changes, it is estimated that up to two-thirds of the world's population could face water scarcity by 2030. Addressing this scenario requires urgent actions, such as the rational use of water, the expansion of basic sanitation, investment in reuse technologies, and sustainable and equitable management of available resources (UNESCO, 2025).

According to Tundisi (2008), the water crisis in the twenty-first century is interpreted in different ways among specialists. While some attribute the problem to poor management of water resources, others point to a combination of environmental, economic and social factors as causes of the worsening. There are also those who criticize the fragmented and reactive management models, focused exclusively on emergency solutions, instead of more effective systemic approaches.

Tropical regions with hot and dry climates are the most affected by water scarcity, especially the semi-arid region of the Brazilian Northeast. In this area, evaporation exceeds

precipitation during most of the year, intensifying the water deficit and favoring the salinization of the soil and underground aquifers.

In response to this scenario, the UN established Sustainable Development Goal 6 - SDG 6 (UN, 2025), which aims to ensure universal access to drinking water and sanitation by 2030. However, the latest data indicates that 2 billion people still live without safe access to water, and 3.6 billion are deprived of basic sanitation (UNESCO, 2024). In addition, 10% of the world's population lives in countries with high or critical water stress, and global demand for water is expected to grow between 20% and 30% by 2050, threatening 45% of the world's GDP and 40% of cereal production (UNESCO, 2023a; UNESCO, 2023b).

To face these challenges, it is essential to recognize the water potentials of each region, considering their physical and climatological characteristics. Groundwater, exploited in a sustainable way, can represent a strategic solution for populations in areas of difficult access or with severe scarcity, as pointed out by Razzolini and Güntherpnud (2008). This alternative is especially relevant in the interior of Pernambuco, where hundreds of low-income families face severe limitations in the supply of drinking water. It is a complex issue that requires integrated actions — economic, social, structural, environmental, and technological — to mitigate its effects.

Historically, the government has responded to droughts with emergency measures, such as work fronts, distribution of basic food baskets and water supply by water trucks. While necessary at critical moments, these actions do not offer lasting solutions. Structuring policies such as the construction of dams, dams, pipelines and the drilling of wells are being implemented, but they do not reach all families, many of whom still face irregular access to essential services, including desalination systems.

The use of desalination plants is essential, given the high salt content present in groundwater. In this context, the Fresh Water Program, created by the Federal Government in 2004, stands out as the most successful initiative in terms of management and sustainability. Despite the challenges, the program has expanded access to drinking water in previously underserved communities.

Therefore, this study reaffirms the relevance of desalination systems as a structuring solution to face water scarcity in Pernambuco. The strengthening of decentralized, participatory and sustainable management is essential, with the Fresh Water Program standing out as the most effective public policy in this confrontation.

1.1 OBJECTIVE

This article aims to address desalination systems aimed at the production of drinking water to serve rural populations in the semi-arid region, with emphasis on the production of water in the semi-arid region.

2 THEORETICAL FRAMEWORK

By addressing desalination systems, this study highlights that this technical process of groundwater exploration and treatment has social, environmental, and structural implications. Socially, it aims to serve populations with difficulties in accessing drinking water, whose absence entails serious risks to health and survival. Environmentally, the waste generated by desalination, when released into nature without proper treatment, causes significant damage to the environment. Structurally, it is observed that most of the systems have problems of discontinuity in the supply of desalinated water with satisfactory quality, due to the absence of preventive and corrective maintenance of the equipment, resulting in stoppages and deterioration.

The search for solutions to these problems refers to the fundamental axes of management, sustainability and social participation, as a basis for a structuring public policy aimed at the requalification of desalination systems in the Brazilian semi-arid region.

2.1 MANAGEMENT

Consulting Ferreira (1986) we find the following definition of Management:

> Originating from the Latin term "gestione", the word management brings the sense of managing, management, administration or direction.

For Oliveira (2006) this concept has the following meaning:

> The chain of processes from the stimulation of covenants, their regulations and the corresponding publication can be controlled and measured. This control and measurement is called management. The concept can be applied to any type of human activity.

Dias (2002) makes a distinction between Administration and Management. For him, the former is a component (function) of the latter. Thereby:

> To manage is to plan, organize, direct, and control people to efficiently and effectively achieve the goals of an organization.
> ... But management incorporates administration and makes it one more of the functions necessary for its performance.
> [Therefore,] management is making use of all the functions[2] and knowledge[3] necessary t achieve the objectives of an organization efficiently and effectively through people.

Concisely, the term "management", for Ferreira (1986), refers to the act of managing, administering or directing. Oliveira (2006) adds that management is the process of control and measurement of human activities, applicable to any type of organized action. Dias (2002) distinguishes management from administration, considering the latter as a function of the former. For him, managing is planning, organizing, directing and controlling people to achieve organizational objectives efficiently and effectively. Management, on the other hand, incorporates these functions and involves the use of all the necessary knowledge to achieve objectives through people.

In view of these citations, the subtle differences in the conceptualization of management among the authors are evident. Thus, the expanded concept of management proposed by Dias (2002) is adopted in this study, which contemplates both the technical and human aspects of organizational conduction.

2.2 SUSTAINABILITY

The concept of sustainability is related to the theme of the environmental issue in the use of natural resources. In this sense, three concepts were selected that essentially have the same meaning, although with peculiar views.

For Schultink (1991),

> Sustainable development can be defined as development with a management of natural resources that can ensure or increase the long-term production capacity of basic resources, and that also ensures the improvement of long-term health and well-being derived from the use of resources from alternative systems, with tolerable environmental impacts.

According to Heal and Kunreuther (2003),

[2] Technical, accounting, financial, commercial, security and administration.
[3] Psychology, anthropology, statistics, marketing, environmental, etc.

> Sustainability is the symmetrical treatment of the present and the future between generations and this treatment assumes positive values for the stock of natural resources in the long term. Sustainability is the explicit recognition of the intrinsic values of environmental resources.

Constanza and Wainger (1991) define sustainability,

> [as] the intensity of consumption of a given natural resource that can be sustained indefinitely without degrading the stock of natural or initial capital

In summary, for Schultink (1992), sustainable development is defined as the management of natural resources in order to guarantee or expand their productive capacity in the long term, also ensuring health and well-being with tolerable environmental impacts. Heal and Kunreuther (2003) add that sustainability implies a symmetrical treatment between present and future, recognizing the intrinsic values of environmental resources. Constanza and Wainger (1991) state that sustainability lies in the intensity of the consumption of natural resources that can be maintained indefinitely without compromising the stock of natural capital.

These definitions converge on the idea that sustainability involves the optimal use of natural resources and responsible environmental management over time, ensuring the needs of current generations without compromising future ones.

2.3 SOCIAL PARTICIPATION

Social participation is understood as a central instrument for the democratization of public policies. This understanding is based on the statements shared by the following authors:

Bispo Júnior and Sampaio (2008), when studying health policy in Brazil and the Unified Health System (SUS), make the following considerations regarding social participation:

> The concept of participation is not univocal and has changed in different periods and contexts ... In Latin America, several authors ... point to the evolution of the concept of participation as a mechanism for the redistribution of power in society.
> In Brazil, with the promulgation of the 1988 constitution (6), community participation became one of the fundamental requirements for the implementation and consolidation of the Unified Health System (SUS). In 1990, laws 8080/90 (7) and 8142/90 (8) were published, which institutionalize and regulate popular participation and social control in health management, with health conferences and councils as legally instituted bodies. Also from the legal point of view, in 2003, the National Health

Council (CNS) published Resolution 333/2003 (9), which establishes parameters for the organization and structuring of health councils. These councils are of a permanent and deliberative nature and their function is to act in the definition of public policies and in the monitoring of management, including economic and financial attributions (8, 9).
However, the existence of this legal apparatus does not guarantee democratic management or participation in the SUS. On the determinants of the participatory process, Cortes ... highlights as most influential the organization of the local population and the willingness of the authorities to respect and encourage collective decisions. Some studies... have demonstrated the difficulty of exercising social participation due to weakness in these factors.
Based on the results of this study, some suggestions are presented in order to contribute to the strengthening of the exercise of social participation in the health area, especially in rural areas. The training of counselors [health councils] must occur on a continuous basis, valuing the local reality and encouraging cohesion and mobilization of popular representation entities. Mechanisms for the involvement of other segments of society, which are still silent on issues related to the SUS and public health, should be considered. Finally, initiatives to raise awareness and train managers are suggested, so that popular participation and collective decision-making spaces can be better valued and respected.

For Valla (1998),

In general, popular participation comprises the multiple actions that different social forces develop to influence the formulation, execution, inspection and evaluation of public policies and/or basic services in the social area (health, education, housing, transportation, basic sanitation, etc.) [emphasis added] ...
This participation, if on the one hand legitimizes the policy of the State before the population, also opens a channel for popular entities to dispute the control and destination of public funds.

Milani (2008),

... In the 1990s, social participation became one of the organizational principles, acclaimed by national and international agencies, of the processes of public policy formulation and democratic deliberation at the local scale. Fostering the participation of different political actors and creating a network that informs, elaborates, implements and evaluates public policies are, today, essential pieces in the discourses of any public policy (self) considered progressive.
Social participation, also known as citizens' participation, popular, democratic, communitarian, among the many terms currently used to refer to the practice of including citizens and CSOs [civil society organizations] in the decision-making process of some public policies, has been erected into a political-administrative principle. Fostering the participation of different social actors in a broad sense and creating a network that informs, elaborates, implements and evaluates political

> decisions has become the paradigm of numerous local development projects (self) qualified as innovative and local public policies (self) considered progressive.
> Social participation implies putting the decision up for debate (Avritzer, 2003; Dagnino, 2002). It is a democratic reform of the State and its public administration, which would be based on the need to stimulate the participation of different actors (governmental and non-governmental), giving equal emphasis to the participation of citizens in defining the conditions of their organization and association.

In summary, for Bispo Júnior and Sampaio (2008) the concept of participation has evolved as a mechanism for the redistribution of power in society. In Brazil, the Federal Constitution of 1988, together with Laws No. 8,080/1990 and No. 8,142/1990, institutionalized popular participation and social control in health management, through conferences and health councils. Resolution No. 333/2003 of the National Health Council reinforces this structure, attributing a deliberative and permanent character to the councils. Valla (1998), on the other hand, defines popular participation as the set of actions developed by social forces to influence the formulation, execution and evaluation of public policies and basic services. Milani (2008) observes that, since the 1990s, social participation has become an essential organizational principle in the processes of public policy formulation, and mentions Avritzer (2003) and Dagnino (2002) who argue that participation implies putting decisions into debate, promoting a democratic reform of the State and public administration.

Thus, social participation, understood as the active involvement of citizens and civil society organizations, is fundamental for the collective construction of public policies and for the implementation of democratic practices.

In summary, the theoretical understanding of management, sustainability and social participation is fundamental for the present study, since when dealing with desalination systems and their importance for significant portions of the rural society of the state, it is evident that such aspects are essential for the restructuring and qualification of the aforementioned systems, as a way to ensure in an effective and socially and environmentally responsible way, the effectiveness of drinking water supply.

3 METHODOLOGY

From a methodological point of view, this work contributes by adopting a robust interdisciplinary and documentary approach, which integrates technical, legal, academic, and institutional sources — from printed diagnoses and government reports to articles indexed in Scielo Brazil and legislation accessed on official portals. This triangulation allowed a

contextualized analysis of the water reality, strengthening the understanding of the challenges of implementing public policies in the semi-arid region.

The methodology used in this study consisted of a qualitative approach based on bibliographic and documentary research. The survey was carried out between the months of May and July 2025, with the objective of identifying relevant productions on the subject of this article.

The following descriptors and keywords were used: drinking water; crystalline basement, desalination; Brazilian semi-arid region; public management; social participation; sustainability; Fresh Water Program.

Materials that did not directly address the theme or were outside the defined temporal scope were excluded.

3.1 LITERATURE RESEARCH

- Scielo Brasil and Google Scholar academic databases were consulted.
- The inclusion criteria involved publications between 2004 and 2025, written in Portuguese, with access to the full text. However, the conceptual bibliographies were accessed at an earlier time (2009) to support a similar theme (TCC Specialization).

3.2 DOCUMENTARY RESEARCH

- Official documents from agencies such as (e.g., MIDR, IBGE, SGB, UN, DNOCS, Embrapa, IPA, SRHS/PE, APAC, CREA/PE, ANA) were analyzed, as well as technical reports and relevant legislation.
- The documents were selected based on their institutional relevance, reliability, and date of publication.
- The analysis of the materials followed an interpretative approach, seeking to extract thematic categories related to the object of study.

4 CONTEXT AND DEVELOPMENT

4.1 BRAZILIAN SEMI-ARID REGION

The Brazilian semi-arid region is marked by climatic and edaphological factors that contribute significantly to water scarcity for much of the year, causing critical periods of drought, which compromise the socioeconomic and environmental development of the region (SUDENE, 2024).

The area currently delimited by the Deliberative Council of the Superintendence of Development of the Northeast (CONDEL/SUDENE), through Resolution No. 176/2024, covers approximately 1,477 municipalities distributed among 11 states: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais and Espírito Santo. This region represents 15.3% of the national territory and is home to about 31 million inhabitants, 37.8% of whom are the Brazilian rural population (IBGE, 2022).

According to the criteria used for the delimitation of the semi-arid region by the Ministry of National Integration (MI) and the Ministry of the Environment (MMA), the municipalities included in this region have at least one of the following characteristics: a) average annual rainfall of less than 800 millimeters; b) aridity index of up to 0.5, calculated by the water balance, which relates precipitation and potential evapotranspiration; and c) drought risk greater than 60%, based on historical series.

Rainfall occurs predominantly between the months of December and May, with average volumes between 200 mm and 800 mm per year, and may exceed 1,000 mm in areas of specific microclimate (ANA, 2023). Even so, the distribution is irregular, both temporal and spatial, and the occurrence of prolonged and unpredictable droughts is common.

In addition to the rainfall scarcity, the potential for evapotranspiration in the region exceeds 3,000 mm per year, due to high temperatures, low relative humidity and sparse vegetation cover. The soils, predominantly shallow and sandy, have a low water retention capacity, which contributes to the intermittency of watercourses, mostly characterized as temporary rivers (FUNCEME, 2023).

The geological basement of the Brazilian semi-arid region is predominantly crystalline, composed of igneous and metamorphic rocks, with generally shallow soils (average depth of 0.60 m), low infiltration capacity, high surface runoff and reduced natural drainage. Groundwater, when present, is stored in rock fractures, forming the so-called fractured or fissural aquifers (CPRM, 2017; EMBRAPA, 2021).

This hydrogeological province is characterized by the occurrence of waters with high levels of total dissolved solids (STD), often higher than 2,000 mg/L, especially in areas of crystalline basement. Recent studies indicate that about 70% of wells drilled in crystalline rocks have salinized waters, with average STD values around 3,000 mg/L, which compromises potability and can pose risks to human health, such as hypertension and gastrointestinal disorders (EMBRAPA, 2021; ANA, 2023).

The high mineralization of the water occurs due to the intense evaporation, common in the semi-arid climate, which concentrates the dissolved salts before, during and after infiltration into the soil. In addition, crystalline aquifers function as discharge sectors for underground flows, receiving water already enriched by saline concentration processes (CPRM, 2017).

According to CONAMA Resolution No. 357/2005, waters with less than 500 mg/L of STD are classified as fresh waters, while waters with dry residue greater than 7,000 mg/L are considered unsuitable for any use. The Maximum Potable Value (VMP) established by Ordinance GM/MS No. 888/2021 is 1,000 mg/L of STD.

The annual water availability per inhabitant in the northeastern semi-arid states varies between 1,320 m³/inhabitant/year (Pernambuco) and 1,781 m³/inhabitant/year (Rio Grande do Norte), below the limit of 2,000 m³/inhabitant/year recommended by the United Nations (UN) as a minimum to ensure sustainable development (ANA, 2023).

As for the biological aspect, the typical vegetation is the Caatinga, the only exclusively Brazilian biome, composed of xeromorphic species, with leaves modified into thorns, thick cuticles and succulent stems for water storage. The roots are superficial, allowing rapid absorption of water from sporadic rainfall (INSA, 2024). However, this vegetation has been severely altered, with the loss of about 8.6 million hectares of native vegetation, equivalent to 14% of the original cover of the biome (MAPBIOMAS, 2025). The use of burning for soil preparation, conversion to pastures, and the removal of wood for firewood and charcoal continue to be common practices among local communities.

Regarding fauna, the Caatinga biome has a wide diversity of fauna, with recent records pointing to approximately 1,800 species of vertebrate animals, including 386 species of fish, 98 of amphibians, 548 of birds and 170 of mammals, about 15% of which are endemic. However, due to strong anthropogenic pressure, such as predatory hunting and deforestation, many of these species are threatened with extinction.

This picture of environmental degradation has compromised water resources, with a predominance of salinized groundwater, shallow and stony soils and scarcity of surface water. This severely limits the sources of livelihood, especially for the rural population.

In turn, the semi-arid region in Pernambuco corresponds to about 87% of the territory, covering the mesoregions of the Sertão and a significant part of the Agreste, which predominate with rainfall between 400 mm and 1,000 mm, with high spatial and temporal

variability (UFPE, 2025) and average annual temperatures ranging between 20°C and 27°C (APAC, 2025).

The rainy season in the Agreste, as a region of climatic transition, with subhumid and semi-arid characteristics, occurs between April and July, with annual totals between 600 mm and 1,000 mm. In the Sertão, the climate is predominantly dry. Annual rainfall varies between 400 mm and 800 mm, concentrated between January and April. Outside this period, the actual and potential evaporation values exceed the average monthly rainfall, resulting in a sharp water deficit (INPE, 2025).

The crystalline basement occupies about 84% to 85% of the territory of Pernambuco, predominating in the semi-arid regions of the Sertão and Agreste (COSTA FILHO, W. D.; COSTA, W. D, 2025), with aquifers present in their fissures and fractures. Groundwater is generally brackish, used for animal consumption and extracted by tubular wells up to 60 m deep.

4.2 WATER RESOURCES IN PERNAMBUCO

The State of Pernambuco has a macro water distribution system, composed of pipelines, reservoirs and treatment plants, with the objective of meeting the demands of human consumption, agricultural and industrial production. This infrastructure is managed by state and federal entities, such as Compesa, DNOCS, and the Ministry of Integration and Regional Development (SRHS-PE, 2025; DNOCS, 2025).

In the semi-arid region of Pernambuco, the pipeline system has prioritized serving urban centers and rural production units located close to existing distribution networks. Initiatives such as the Agreste Pipeline, the Alto Capibaribe Pipeline, the Serro Azul Pipeline and the Negreiros Pipeline System stand out, which aim to expand access to water in regions historically affected by water scarcity (DNOCS, 2025).

Despite the advances, the current distribution network is still insufficient to fully serve the prioritized areas and expand the offer to diffuse rural communities, especially in the Sertão and Agreste. It is estimated that much of the rural area will continue without adequate coverage, even with the projects in progress.

Water use in the semi-arid region of the state is limited due to the predominance of temporary rivers, the low density of reservoirs, and the morphological conditions unfavorable to the construction of large dams (DNOCS, 2025). Most of the available water is extracted from small dams and wells, with low flow and variable quality.

As for groundwater availability, the aquifers with the greatest hydrogeological potential are located in the coastal sedimentary basins of Pernambuco, in addition to the interior basins of the Jatobá and Araripe, located in the semi-arid region of the state (COSTA FILHO, W. D.; COSTA, W. D.; SILVA, G. D., 2012).

These basins have sandstone formations with high porosity, favoring the storage and quality of groundwater.

In addition to these, there are small sedimentary basins with potential that has not yet been studied, such as São José do Belmonte, Mirandiba, Betânia, Fátima, Araras, Carnaubeira da Penha and Cedro, all located in the Pajeú region (ABAS, 2025).

The Tacaratu Aquifer System, located in the Jatobá Basin, has significant reserves, but its exploitation is still incipient in municipalities such as Arcoverde, Buíque and Ibimirim. (CPRM, 2012).

Regarding the fissural hydrogeological domain, represented by the crystalline rocks, it occupies about 84% to 85% of the state territory. Fissural aquifers have low storage capacity, with generally salinized waters, used mainly for animal consumption and extracted by tubular wells up to 60 meters deep (SGB, 2023).

Despite the limitations, the fissural aquifer is strategic, as it is close to the end user and can be used through desalination, especially in diffuse rural communities in the semi-arid region (MIDR, 2025).

According to a survey by the Geological Survey of Brazil (SGB/CPRM) and the Agronomic Institute of Pernambuco (IPA), there are approximately 10,500 tubular wells registered in the state, most of which are located in the semi-arid region. Many of these wells were drilled in critical periods of drought, with inadequate technical execution, short deadlines, and lack of post-drilling monitoring (SGB, 2023; IPA, 2020).

Water conservation and quality conditions vary widely. In many cases, up-to-date data on geographic location, drilling date, flow, and dry residue (STD) are lacking, making it difficult to efficiently manage groundwater resources (ABAS, 2025; CPRM, 2012).

4.3 DESALINATION SYSTEMS

According to Campos (2007), citing Nobre (1985), salinization is a common characteristic in semi-arid areas around the world. However, these areas contain important groundwater resources, which, with the introduction of desalination systems, emerge as a strategic alternative to guarantee water supply in rural communities.

The major problem with groundwater in crystalline rocks in the semi-arid region is the high salt content, with concentrations that often exceed 3,000 mg/L, making them unfit for human consumption and associated with health risks, such as hypertension (OLIVEIRA, 2023; SGB, 2025).

With the advancement of desalination technologies, especially reverse osmosis, the problem of salinity became technically surmountable, allowing the treatment of brackish water to make it drinkable (MIDR, 2025; SGB, 2023). In the Brazilian semi-arid region, this technology is widely used in diffuse rural communities, with systems consisting of a tubular well, pump, feed tank, desalination plant, and drinking water reservoir (SDA, 2025).

The reverse osmosis process consists of passing water through semipermeable membranes under pressure, separating the salts and producing two flows: permeate (drinking water) and tailings (saline concentrate) (OLIVEIRA, 2023). The recovery yield varies between 40% and 60%, depending on the quality of the raw water and the efficiency of the system (CREA-PE, 2025).

However, inadequate tailings management has generated significant environmental impacts, such as increased soil salinization, contributing to the desertification process and making agriculture and native vegetation unfeasible (EMBRAPA, 2023). Studies indicate that tailings require monitoring and safe disposal (UFPE, 2023).

Currently, there are about 300 desalination systems in operation in the semi-arid region of Pernambuco, under the responsibility of the State, DNOCS and FUNASA, distributed in 76 municipalities, with a capacity to serve approximately 165 thousand people (MIDR, 2025; SDA, 2025). In addition to these, there are municipal systems without an updated survey regarding location, state of conservation and operation.

The lack of maintenance, technical training and institutional support has led to the deactivation or precarious functioning of most systems. Problems such as improper disposal of tailings, improper removal of equipment by municipalities and the absence of community management compromise the sustainability and continuity of supply (CREA-PE, 2025; MIDR, 2025).

Faced with the need to expand access to drinking water in the Brazilian semi-arid region and to increase the management of the desalination processes of brackish and saline groundwater, the Federal Government created, in 2004, the Fresh Water Program (PAD), with an emphasis on the introduction of sustainable, environmentally appropriate and socially participatory solutions.

4.4 FRESHWATER PROGRAM: INNOVATIONS AND CHALLENGES IN SUSTAINABLE DESALINATION

Created in 2004, the Fresh Water Program (PAD) has as its main objective to democratize access to drinking water through the desalination of brackish and saline groundwater, benefiting rural communities in situations of socio-environmental vulnerability (MIDR, 2025).

The PAD is coordinated by the Ministry of Integration and Regional Development and developed with states, municipalities and civil society, based on participatory management, community organization, use of renewable energies, incentive to scientific research, environmental recovery and protection of biodiversity (MIDR, 2025).

The PAD is present in 11 Brazilian states: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais, and Espírito Santo, with state technical centers specialized in desalination, environmental management, and community mobilization (MIDR, 2025).

To date, the PAD has implemented 1,068 desalination systems in 298 municipalities in the Brazilian semi-arid region. This initiative, coordinated by the Ministry of Integration and Regional Development, has already benefited approximately 264 thousand people, with an installed capacity to produce about 4.2 million liters of desalinated water per day. In 2025, the program reached a significant milestone: by July, 110 new desalination systems had been implemented. In Pernambuco alone, 70 systems were installed, consolidating the state as a leader in the expansion of the initiative (MIDR, 2025).

The PAD promotes the improvement of desalination systems, with emphasis on the construction of storage tanks for highly saline tailings, avoiding disposal in the environment and consequent environmental degradation (GOVERNO DO BRASIL, 2023). Under appropriate natural conditions, such as soil depth and flow rate greater than 3,000 L/h, the Program has implemented Demonstration Units (DUs), which use saline concentrate for community fish farming and irrigation of saltgrass (Atriplex nummularia), a forage plant intended to feed goats and sheep (EMBRAPA, 2023).

These DUs are configured as Productive Units of technological diffusion, valuing the sustainable use of water resources and integrating productive practices into the desalination process.

The management of the systems is agreed upon through the Management Agreement, an instrument that defines the responsibilities between institutions, communities, and local

governments, ensuring the regular functioning and quality of supply (GOVERNO DO BRASIL, 2023). The Program prioritizes locations with low Human Development Indexes (HDI), lower rainfall, absence of alternative water sources and high infant mortality rates.

Despite the advances and innovations, the Program still faces strategic challenges to integrate desalination with other modalities of water use, such as water reuse, rainfall harvesting and the use of sedimentary aquifers, seeking to consolidate the process from an economic, social and environmental perspective.

5 RESULTS AND DISCUSSION

5.1 SOCIAL, ENVIRONMENTAL AND STRUCTURAL IMPACT

- Desalination systems have been fundamental to ensure drinking water in areas of socio-environmental vulnerability, combating health risks and promoting dignity.
- However, the literature points to structural weaknesses, such as failures in equipment maintenance, resulting in interruptions in water supply and low operational efficiency.
- Environmentally, the improper disposal of saline tailings is a critical point. The practice can generate contamination and loss of biodiversity, requiring more sustainable solutions and constant monitoring.

5.2 TECHNICAL AND ORGANIZATIONAL REQUALIFICATION

- The Fresh Water Program (PAD) acts directly to mitigate these problems, with investments in infrastructure, such as tailings tanks and Demonstration Units that reuse saline concentrate in productive activities (e.g. fish farming and animal fodder).
- These advances promote environmental and productive revaluation of tailings, consolidating an integrative approach between conservation of water resources and local economic sustainability.

5.3 PARTICIPATORY MANAGEMENT

- The agreement via Management Agreements between communities and institutions reinforces the role of expanded management, as defined by Dias (2002), which contemplates the technical and human dimensions of public administration.
- This community management strengthens local governance, improving the operation of systems and ensuring greater cultural and functional adherence.

5.4 ENVIRONMENTAL SUSTAINABILITY

- The PAD has adopted strategies aligned with the principles of Schultink (1992) and Heal and Kunreuther (2003), promoting actions that respect the balance between current consumption and future preservation of natural resources.
- The practice of irrigation with treated wastewater and the use of renewable energies in desalination units demonstrates an applied sustainable development model.

5.5 SOCIAL PARTICIPATION AS A DEMOCRATIC PILLAR

- The role of civil society in the formulation and evaluation of public policies for water supply is essential to ensure legitimacy, transparency and social justice.
- The PAD incorporates this perspective through community organizing and social mobilization, integrating communities into decision-making and operational processes.

5.6 SUMMARY

The data reveal that, despite the technical and environmental challenges, the advances promoted by the PAD signal a systemic evolution in public desalination. The intersection between integrated management, sustainable practices, and social participation reveals a solid path to transform desalination systems into structuring policies that promote water citizenship in the Brazilian semi-arid region.

6 CONCLUSIONS AND CONTRIBUTIONS

Desalination systems represent a viable and necessary alternative for regions affected by water scarcity, especially in the semi-arid region of Pernambuco. However, its effectiveness depends on multiple factors, such as efficient management, community participation, environmental sustainability, and institutional continuity.

The Fresh Water Program has transformative potential, but requires strengthening of monitoring strategies, local training and articulation with complementary public policies. The integration between technical documents, academic bases and legal norms, as applied in this research, contributes to a deeper understanding of the regional water reality and to the improvement of future actions.

The documentary and bibliographic analysis carried out in this study demonstrates that desalination systems in the semi-arid region of Pernambuco constitute a relevant technical response to the persistent water scarcity in the region. However, the efficiency of these

technologies is strongly conditioned by the quality of local management, community training policies and the continuous monitoring of operating conditions.

The Fresh Water Program stands out as a strategic initiative of an intergovernmental nature, promoting not only access to drinking water, but also sustainable practices in the management of saline tailings and community organization. The incorporation of participatory and environmental guidelines gives the program an important differential compared to other specific actions.

The expansion of desalination systems, with the design and methodology of the Fresh Water Program, which associated with social, environmental and technical management policies, represents a promising way to solve the challenges of access to drinking water in the semi-arid region of Pernambuco. The effectiveness of these systems depends on the strengthening of integrated actions, with the active participation of communities and support from government entities.

To achieve continuous efficiency, it is necessary to define a multi-institutional arrangement of decentralized and regionalized management, integrating communities, public agencies and civil society under a framework that prioritizes this desalination system as one of the central axes of sustainable rural supply for diffuse populations.

Finally, the research reinforces the need to broaden the debate on the universalization of access to drinking water, and proposes that the strengthening of local arrangements, associated with long-term strategies, is essential to transform desalination systems into sustainable and socially just solutions.

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