ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 11, nº 1 (2025)

https://doi.org/10.21680/2447-3359.2025v11n1ID36217

Expanding water supply in the semi-arid region: reducing evaporation and desalination

Ampliação da oferta de água no semiárido: uma revisão da redução da evaporação e dessalinização

Maria das Graças Monteiro Almeida de Melo1; Thaísa Mayane Tabosa da Silva2; Karinne Martins Batista3; Simone Rosa Silva4; Antonio Celso Dantas Antonino5; Jaime Joaquim da Silva Pereira Cabral6; Anderson Luiz Ribeiro de Paiva7

[1] Master's in Civil and Environmental Engineering from the Graduate Program in Civil and Environmental Engineering (PPGECAM), Federal University of Pernambuco (UFPE), Caruaru-PE, Brazil. Email: gracas.melo@ufpe.br
ORCID: https://orcid.org/0000-0002-1289-2531

[2] Master's in Civil and Environmental Engineering from PPGECAM/UFPE, Caruaru-PE, Brazil. Email: thaisa.tabosa@ufpe.br
ORCID: https://orcid.org/0000-0002-7771-3039

[3] Master's student in Civil and Environmental Engineering from PPGECAM/UFPE, Caruaru-PE, Brazil. Email: karinne.martins@ufpe.br
ORCID: https://orcid.org/0009-0009-4308-6282

[4] Associate Professor of the Department of Civil Engineering at the University of Pernambuco (UPE), Recife-PE, Brazil. Email: simonerosa@poli.br
ORCID: https://orcid.org/0000-0001-7138-7546

[5] Full Professor of the Department of Nuclear Engineering (DEN) at UFPE, Recife-PE, Brazil. Email: antonio.antonino@ufpe.br
ORCID: https://orcid.org/0000-0002-4120-9404

[6] Associate Professor of the Department of Civil Engineering at the University of Pernambuco (UPE), Recife-PE, Brazil. Email: jaime.cabral@ufpe.br
ORCID: https://orcid.org/0000-0002-1348-8004

[7] Associate Professor of the Department of Civil and Environmental Engineering (DECIV) at UFPE, Recife-PE, Brazil. Email: anderson.paiva@ufpe.br
ORCID: https://orcid.org/0000-0003-3475-1454

Abstract: With low and irregular rainfall and high evaporation rates, semi-arid regions are constantly dealing with problems arising from negative water balance. In several rural locations, the aquifer is the primary source of available water; however, most of it is composed of a high concentration of salts. Thus, the objective of this article is to carry out a literature review in the SciELO, Science Direct, Scopus and Web of Science databases, which presents techniques for inhibiting evaporation of surface water and desalination of aquifers. Physical, chemical, and biological methods are indicated to reduce the evaporation of surface water bodies. Solutions that use physical coverings are the most advantageous because they provide excellent reductions, which can reach 85%, and because of the ease of access that populations have to the material. For desalination, thermal and membrane processes are presented, where, for brackish waters, reverse osmosis stands out since it provides advantages such as low energy consumption, constant quality of produced water, and a range of salinity reduction more significant than 80 %. Therefore, the techniques for suppressing evaporation and desalination show efficiency, standing out as processes of extreme relevance in reducing water salinity, which is fundamental for supplying diffuse communities.

Keywords: Water resource; Reverse osmosis; Floating cover; Aquifer; Diffuse community.

Resumo: Com a baixa e irregular pluviosidade e as altas taxas de evaporação, regiões semiáridas lidam constantemente com os problemas decorrentes do balanço hídrico negativo. Em diversas localizações rurais, a principal fonte de água disponível é o aquífero, contudo, em sua maioria é composta por alta concentração de sais. Assim, o objetivo deste artigo é realizar uma revisão de literatura nos bancos de dados SciELO, Science Direct, Scopus e Web of Science, que apresente técnicas de inibição da evaporação das águas superficiais e de dessalinização de aquíferos. Para a diminuição da evaporação de corpos hídricos superficiais são apontados os métodos físicos, químicos e biológicos. As soluções que utilizam coberturas físicas, são as mais vantajosas por proporcionarem excelentes reduções, que podem chegar a 85%, e pela facilidade de acesso que as populações têm ao material. Para a dessalinização são apresentados os processos térmicos e por membranas, onde, para as águas salobras se destaca, a osmose reversa, uma vez que proporciona vantagens como baixo consumo energético, qualidade constante de água produzida, e alcance de redução de salinidade superior a 80%. Logo, em conjunto as técnicas de supressão da evaporação e de dessalinização mostram eficiência, destacando-se como processos de extrema relevância quanto à diminuição da salinidade das águas, fundamental para o abastecimento de comunidades difusas.

Palavras-chave: Recurso hídrico; Osmose reversa; Cobertura flutuante; Aquífero; Comunidade difusa.

Received: 06/05/2024; Accepted: 09/04/2025; Published: 22/04/2025.

1. Introduction

Arid and semi-arid regions face difficulties regarding of water availability to supply the population. The Brazilian semi-arid region typically has a rainfall regime marked by scarcity, irregularity, and precipitation concentration over a short period, with insufficient volumes of water in its springs to meet the population's needs (SILVA et al., 2010).

Average reference evapotranspiration can reach 2,500 mm.year^{-1} in these locations, generating high water deficits (MONTENEGRO; MONTENEGRO, 2012) and significant fluctuations in surface water availability (PBMC, 2014). Regarding groundwater sources, the Brazilian semi-arid region is made up of alluvial aquifers and a system of crystalline aquifers with low hydrogeological potential, which in turn compromise the quantity and quality of these waters (SANTOS et al., 2009). The occurrence of these waters in northeastern Brazil, the territory is made up of more than 80% crystalline rocks, with a predominance of waters with a high salt content as a natural condition (CIRILO, 2008), or due to problems arising from the salinization process (KREIS et al., 2020). Thus, the desalination technique is highlighted when treating these brackish groundwaters, in search of their potability.

Researchers have therefore been studying ways to meet water demand by using techniques such as groundwater exploration (OYEYEMI et al., 2018; KOUADIO et al., 2020; AMATO et al., 2021), conservation of fresh surface water (GALLEGO-ELVIRA et al., 2011; HAAS et al., 2020; LOPES et al., 2020), desalination of brackish water, seawater, wastewater and the application of treated domestic effluents in agriculture (BEJJANKI et al., 2021; BLAZYTE et al., 2021; MOHARRAM et al., 2021; STEIN et al., 2021).

In addition, water bodies can have their salinity characteristics modified by evaporation processes (CARTWRIGHT et al., 2013; RAJMOHAN et al., 2021), mineral weathering (GAMBOA et al., 2019; RAJMOHAN et al., 2021), ion exchange (RAJMOHAN et al., 2009), saline water intrusion (RAJMOHAN et al., 2009; HAN et al., 2011), anthropological factors through waste dumping and contamination (MONDAL; SINGH, 2011), agricultural activity (ZIADI et al., 2019), transpiration from deep-rooted vegetation, the influence of soil type and also due to the hydrogeological dynamics of the aquifer. It is worth noting that the transpiration of deep-rooted vegetation has no impact on the salinity of groundwater and deep aquifers, due to the limited length and distribution of the roots (LIU et al., 2018).

Of the factors mentioned above, evaporation and the process of mineral weathering are some of the main mechanisms that alter the salinity of an aquifer in semi-arid and arid climates (SUN et al., 2016; LIU et al., 2018; RAJMOHAN et al., 2021). Thus, Tan et al. (2020) highlight the weathering process as one of the possible origins of salinization in groundwater, which can influence the growing demand for fresh water. Water quality is influenced by the fractions of water that percolate through the various rocks that undergo weathering, i.e. the rocks' characteristics affect the water's final composition.

Furthermore, Pereira et al. (2006) state that in the reservoirs of the semi-arid region of Brazil, the waters are becoming more saline and, in some cases, have concentrations of salts that make them unsuitable for human consumption and agriculture; this occurs during the dry season due to the high rates of evaporation. Concerning surface waters, it is known that these are recharged by rainwater and are subsequently affected by evaporation, which alters both the concentration of ions and the stable isotopes of these bodies of water (YANG et al., 2020).

In this context, the present study aims to analyze techniques for reducing evaporation in open-air reservoirs and applying membrane desalination for aquifers, to lower salinity levels and ensure water availability for dispersed communities in the Brazilian semi-arid region.

2. Methodology

The methodology consists of a literature review conducted to update the state of the art on methods for evaporation mitigation and techniques for desalination of water in reservoirs of arid and semi-arid regions.

The present study was conducted based on a compilation of 62 works from both national and international literature, including journals, magazines, theses, and dissertations from available databases (SciELO, Science Direct, Scopus, and Web of Science), published between 2002 and 2025. For data processing in the research, the following keywords were used: water resources, water quality, brackish water, desalination units, reverse osmosis, semi-arid, floating cover, aquifer, and dispersed community.

It is noteworthy that the advantages and disadvantages of each physical barrier method used, as well as desalination techniques, were considered to identify the best characteristics and possibilities for expanding the water supply in the Brazilian semi-arid region.

3. Reduction of evaporation as a technique for preventing high salinity concentration

Evaporation suppression techniques began to be applied in the 1960s, with monomolecular films being used as protective layers on water surfaces to reduce evaporation. Subsequently, other techniques were developed, categorized into three main methods: physical, chemical, and biological.

Physical methods are subdivided into floating covers and suspended covers (HASSAN et al., 2015; SIMON et al., 2016; TABOADA et al., 2017), which provide the highest evaporation reduction rates (Table 1); chemical methods, such as monomolecular films (GALLEGO-ELVIRA et al., 2013; SOVOCOOL, 2014; MOZAFARI et al., 2019); and biological methods, which include aquatic plant covers, windbreaks, among others (JAT et al., 2010; ALHASSOUN et al., 2011; ORIBI; ABDULKAREEM, 2020). In addition to these techniques, some studies have explored the potential of thermal mixing systems with artificial aeration to reduce evaporation (HELFER et al., 2018).

Jat et al. (2010) and Hassan et al. (2015) assert that reducing evaporation losses in open water reservoirs is crucial for improving water security in arid and semi-arid regions, where primary water sources consist of a large number of small agricultural dams. Consequently, minimizing water losses from such dams is essential for the economic viability of agricultural production.

3.1. Physical methods: Application of suspended elements

The suspended elements used in studies for evaporation suppression in open-air reservoirs, as presented in Table 1, are polyethylene screens and aluminized screens. Alvarez et al. (2006) compared the use of polyethylene screens in various colors and layer quantities with aluminized screens. They found that shading resulting from the use of these screens led to a significant reduction in daily evaporation rates, ranging from 50% for the aluminized screen to results between 54.7% (single-layer white polyethylene screen) and 83.5% (double-layer black polyethylene screen) for the polyethylene screens (ALVAREZ et al., 2006).

Covering with polyethylene screens provides benefits to the properties of stored water, such as the reduction of algae growth due to the lack of sunlight, prevention of debris deposition, and lower salinity concentration in the water volume when the balance between rainfall and evaporation is positive (GALLEGO-ELVIRA et al., 2011). Furthermore, operation and maintenance costs are very low and only arise in extraordinary situations (MARTINEZ-ALVAREZ et al., 2010), with the system's lifespan ranging from 10 to 15 years (ALVAREZ et al., 2006). Thus, Martinez-Alvarez et al. (2010) state that this technique can be economically viable in small agricultural reservoirs.

The feasibility of using polyethylene screens for evaporation reduction still requires further analysis, particularly regarding climate and reservoir variability. Since the studies were conducted over one year, the long-term impact on water quality should still be better evaluated. Nonetheless, the technique has proven effective and easy to install, making it an attractive option for water conservation in rural properties.

Table 1 – State of the art on evaporation reduction techniques based on physical methods.

Reference	Technique	Reservoir	Region	Coverage rate	Observation period	Seasons	Evaporation rate	Evaporation rate reduction
Alvarez et al., 2006	Polyethylene screen	Class-A Tank	Southeast of Spain	100% coverage by the screen (1)	May to September 2003.	Summer	-	Average daily reduction factor of 54,7% to 83,5%.

Martinez-Alvarez et al., 2010	Polyethylene screen	Agricultural Reservoir - 2400 m² with a depth of 5 m and a maximum width of 55 m. Storage capacity of 11,920 m³.	Southeast of Spain (semi-arid)	100% coverage by the screen (1)	1 year covered and 1 year uncovered.	All seasons	1190.98 mm/year (uncovered); 191.59 mm/year (covered)	Average annual reduction factor of 84,1%.
Gallego-Elvira et al., 2011	Polyethylene screen	Agricultural Reservoir - 2400 m² with a depth of 5 m and a maximum width of 55 m.	Southeast of Spain (semi-arid)	100% coverage by the screen (1)	1 year covered and 1 year uncovered.	All seasons	1316 mm/year (uncovered); 194 mm/year (covered)	Annual reduction factor of 85%.
Haghighi et al., 2018	Shade Balls	-	California	64 to 74%	1.5 years	All seasons	-	-
Han et al., 2019	Counterweighted spheres	2 tanks with areas of 1 m².	Xinjiang, China (arid/desert climate)	81%	1 year		2845 mm/year (uncovered); 763.45 mm/year (covered - area of 4 m²) (2)	Reduction of up to 89,6% when wind speed is low (up to 1.5 m/s); and an average reduction of 87,8% (area of 4 m²) (3)
Han et al., 2020	Counterweighted spheres	High-density polyethylene reservoirs with a diameter of 1.2 m and a	Northwest of China	76,4%	8 months - march to october	-	-	70,6% reduction

		height of 0.8 m.						
Sahu et al., 2016	Floating Photovoltaic Cover	-	Asia-Pacific, Europe, Japan, China, and India.	-	-	-	-	70% reduction
Padilha Campos Lopes et al., 2020	Floating Photovoltaic Cover	Reservoirs of the Apodi Basin / Mossoró, RN.	Brazilian Semi-Arid	50% and 70%	-	-	1960 mm/year or 5.34 mm/day uncovered; 878.10 mm/year covered ([4])	55,2% reduction
Haas et al., 2020	Floating Photovoltaic Cover	Rapel Reservoir, a hydroelectric power plant with a storage capacity of 400 Mm³.	Chile	From 0 to 100%.	2.5 years.	Todas as Estações	-	Up to 16% with 100% coverage.

[1]It is not an effective coverage. No information was provided about the mesh of the screen;
[2]Information extracted based on a calculation that uses the evaporation rate characteristic of the region as mentioned in the text and the evaporation reduction rate;
[3]Information obtained through the average of the reduction percentages presented in the article;
[4]Calculated based on the volume that is no longer evaporated
Source: Authors (2024).

3.2. Physical methods: Application of floating elements

As floating covers, studies with shade balls (high-density polyethylene plastic spheres with a diameter of around 10 cm, partially filled with water), counterweighted spheres, floating photovoltaic covers, and PET bottles (500 mL) are presented in Table 1. Regarding the use of shade balls, it is noteworthy that their use can be economically viable for long-term installations, as they have a long lifespan and are easy to maintain (HAGHIGHI et al., 2018; HAO et al., 2025). Concerning the deterioration of water quality due to algae proliferation, some experts have raised the hypothesis that the use of shade balls may create a thermal blanket with the potential to promote bacterial growth (STOJSAVLJEVIC JR, 2019; HAGHIGHI et al., 2018).

According to the analysis conducted by Han et al. (2019), counterweighted spheres may be a viable option for increasing water storage for industrial purposes, but they are not economically feasible when the goal is agricultural production. These authors further state that it is unlikely that this material will cause problems associated with the progressive leaching of chemicals, as it is made from high-density polyethylene (HDPE). Both materials, shade balls and counterweighted spheres, use high-density polyethylene as their base material.

Hassan et al. (2015) analyzed the reduction in evaporation resulting from the use of PET bottles with a diameter of 65 mm and observed that evaporation was reduced by 43% in coastal areas and 37% in arid zone areas. The authors emphasize that potential impacts on water quality due to reduced solar radiation and reduced oxygen exchange on the water surface must be determined at a field scale.

The use of floating photovoltaic structures has been applied with the primary goal of producing energy; however, these structures also induce significant evaporation reductions (SAHU et al., 2016; HAAS et al., 2020; LOPES et al., 2020). The economic aspects of floating photovoltaic structures indicate that they have a lifespan of 25 years with an investment payback period of 4 years, considering only the savings from water that would have been evaporated (LOPES et al., 2020).

Regarding water quality, such panels can reduce photosynthesis and algae growth (SAHU et al., 2016). In reservoirs, they decrease dead organic material and bacterial activity, reducing oxygen consumption and the biomass of toxic algae (HAAS et al., 2020). However, with high coverage, the panels may severely limit algae growth, restricting carbon transfer to higher levels and thus affecting the reservoir's ecology.

When comparing the acquisition process of all the materials previously mentioned, purchasing by dispersed populations may be easier and faster for polyethylene screens, as they are products readily available in local markets. The installation of polyethylene screens also does not require specialized labor, which would be challenging for the region of interest. Since no negative impacts on water quality were reported, it can be concluded that using black polyethylene screens constitutes a viable alternative for implementation in small reservoirs of rural communities in the Brazilian semi-arid region.

The techniques presented earlier can effectively reduce the salinity of surface water bodies where they can be applied; however, these techniques are mitigating in terms of preventing salinity in groundwater and may not constitute a single solution. Therefore, the following will present desalination techniques that can be applied as auxiliary solutions for salinity reduction.

4. Desalination techniques

Using desalination units has gained increasing attention, as conventional water sourcing methods are insufficient to meet human consumption needs, especially during drought periods (MOCOCK et al., 2015). Desalination processes aim to remove dissolved salts from water, thus transforming it into water suitable for human consumption. Among the different methods of desalination, the most relevant are thermal desalination processes and filtration using membranes.

Desalination methods are subdivided into two subgroups: thermal processes and membrane processes. Among some of the thermal desalination processes are Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), and Vapor Compression Distillation (VC). Regarding membrane desalination processes, Reverse Osmosis (RO) and Electrodialysis (ED) stand out (GHAFFOUR et al., 2013).

The MSF technique is preferred for large-scale seawater desalination plants, as the seawater intake is approximately double compared to the RO method. However, the process has disadvantages such as higher thermal energy costs, electricity, and other capital expenses, which are more significant than membrane desalination for water production (NAPOLI; RIOUX, 2016; DINCER; DINCER, 2018). Napoli and Rioux (2016) highlight MED as a distillation process to separate fresh water from salt and other impurities, where, through thermal desalination, the residual heat from cogeneration plants can be used, enabling water and energy needs to be met simultaneously from a utility. Regarding the principle of operation of the VC process, there are two different modes of operation in this technique: the vapor compression can be carried out through a mechanical compressor (MVC), or small amounts of high-pressure vapor can be added through an ejector (TVC) (AL-KARAGHOULI et al., 2009).

The desalination process by Osmosis occurs through the phenomenon of water flow through a semipermeable membrane that prevents the transport of salts or other solutes across the membrane. The two aqueous solutions are separated by a semipermeable membrane, where water will flow from the side of lower solute concentration to the side of higher solute concentration. In Reverse Osmosis, the opposite occurs; that is, the liquid moves from the side with a higher salt concentration to the side with a lower concentration due to the reverse path of the natural osmotic method (CHEN et al., 2011). On the other hand, Electrodialysis (ED) is a process based on ion-exchange membranes, between anions and cations arranged in an alternating pattern between an anode and a cathode, with an electrochemical potential acting as the driving force (STRATHMANN, 2010).

Thus, in Table 2, the membrane desalination methods are exemplified, as they are the most commonly used processes compared to thermal methods, using brackish groundwater as the source.

4.1. Reverse Osmosis (RO)

Reverse Osmosis (RO) technology has emerged as one of the cheapest and most promising desalination methods, offering advantages such as low investment cost, environmental criteria, low energy consumption, consistent water quality, continuous operation, flexibility in future installations, and high-quality water characteristics with salt removal efficiency exceeding 80% (WALHA et al., 2007; MOURA et al., 2008; SARAI ATAB et al., 2016; SILVA, 2022).

The economic aspects of the RO process, as exemplified in Table 2, vary according to the individual characteristics of each installation. The cost of desalinated water can start at approximately 0.15 US$/m³ (0.11 £/m³) for a system with a proposed capacity of 24,000 m³/day (SARAI ATAB; SMALLBONE; ROSKILLY, 2016), and reach up to 4.93 US$/m³ (25.00 R$/m³), for a system productivity of 3.6 m³/day (800 L/h) (SALES et al., 2017). The lifespan of the membrane depends on proper operation and maintenance performed throughout the process (SALES et al., 2017), ranging from 5 years (LEE et al., 2002) to as much as 25 years (PIMENTEL DA SILVA; SHARQAWY, 2020).

Table 2 – Summary table of membrane desalination techniques.

Reference	Technique	Source	Chemical analysis	System productivity / operation	Energy consumption	Costs	Region
Walha et al. (2007)	Reverse osmosis	Brackish water	Total Dissolved Solids (TDS) Feed = 2677 mg/L; Permeate TDS = 328 mg/L; Concentrate TDS = 5411 mg/L; Salt Rejection Rate (SRR) > 80%.	-	0.81 kwh/m³	Maintenance and operation cost of 5 to 10% per year of the installation cost.	Gabes - South of Tunisia (Arid to semi-arid climate)
Sarai Atab et al. (2016)	Reverse osmosis	Brackish water	Salinity Feed = 15.168 ppm; Permeate Salinity < 400 ppm; SRR = 88%.	24,000 m³/day / 7884 hours annually	0.8 kWh/m³	Investment Cost = $19.34 million USD (£14.4 million GBP); Fixed Cost = $0.020 USD/m³ (£0.015 GBP/m³); Variable Cost = $0.024 USD/m³ (£0.018 GBP/m³); Water Cost = $0.15	Iraq

						USD/m³ (£0.11 GBP/m³).	
Sales et al. (2017)	Reverse osmosis	Brackish water	-	3.6 m³/day (864 m³/year) / 4.5 hours/day	-	Investment Cost = R$113,960.03 = US$22,485.31; Maintenance and operation cost = R$18,603.50/year (US$3,668.61/year); Water Cost = R$25.00/m³ (US$4.93/m³).	Ceará - Brazil (Semi-arid climate)
Pimentel da Silva; Sharqawy (2020)	Reverse osmosis	Brackish water	TDS Feed = 3,500 mg/L; TDS Permeate = 500 mg/L.	10 m³/day (1.25 m³/h) / 8 hours/day	2.8 kWh/m³	Total annualized cost of the PVRO system = $15,736 and $18,596; Cost of the OR system = $43,620 and $53,686; Cost of the PV system = $12,499 and $16,084; Water cost = $1.44 to $1.65 USD/m³.	
Lee et al. (2002)	Electrodialysis	Brackish water	NaCl concentration in feed = 3500 mg/L; NaCl concentration in permeate = 350 mg/L; Recovery rate > 75%.	350 m³/day / 24 hours/day	0.41 kwh/m³	Membrane and Capital Cost = 150 USD/m².	-
Walha et al. (2007)	Electrodialysis	Brackish water	TDS Feed = 2677 mg/L; TDS	-	0.53 kwh/m³	Maintenance and operation cost corresponding	Gabes - South of Tunisia (Arid to

			Permeate = 500 mg/L.			to 5 to 10% per year of the installation cost.	semi-arid climate)
Wright et al. (2018)	Electrodialysis	Brackish water	Feed concentration = 3451 mg/L; Product concentration = 480 mg/L; Recovery rate = 80%.	Desalination rate = 650 ± 10 L/h	1.13 ± 0.02 kwh/m³	-	

Source: Authors (2024).

4.2. Electrodialysis (ED)

The main application of electrodialysis (ed) is producing drinking water from brackish water, as it offers a greater economic advantage compared to other desalination techniques. However, ED can only remove ions from the drinking water, and non-charged components, such as microorganisms, cannot be eliminated. Therefore, the method becomes less advantageous compared to other membrane processes (LIU; CHENG, 2020).

As shown in Table 2, the study by Lee et al. (2002) reported an energy consumption of 0.41 kWh/m³ for a total membrane area of 753.77 m², while the study by Walha et al. (2007) reported an energy consumption of 0.53 kWh/m³ for a total membrane area of 0.27 m², corresponding to the production of 1 m³ of desalinated water. Both studies highlight the low energy consumption of the process, and this consumption varies depending on the concentration of the brackish water.

Thus, a comparison between the RO and ED techniques was possible. ED showed a more significant reduction in energy consumption than RO processes. However, it proved to be less commonly used due to its limitation of removing only ions from drinking water. The costs associated with both techniques varied depending on the process, region, and intended application. In summary, the techniques demonstrated efficiency in salt removal, especially in brackish groundwater in arid or semi-arid regions.

5. Conclusion

The evaporation suppression techniques presented have a high potential to reduce the salinity of surface water bodies, as they can achieve reductions of up to 89.6% in evaporation rates through the use of physical methods, which are the most effective in minimizing evaporative losses. In general, using floating or suspended covers to reduce evaporation does not compromise water quality due to the progressive leaching of chemical products. However, a high percentage of surface coverage may negatively impact the reservoir's ecology if it severely reduces solar radiation incidence. For diffuse communities in the Brazilian semi-arid region, black polyethylene mesh stands out, as it provides significant evaporation reductions and is more accessible and easier to install under such conditions.

Desalination processes have proven effective for treating groundwater, achieving salinity reductions greater than 80%. Membrane-based processes have shown advantages over thermal desalination methods when treating brackish water, as they are the most used by communities in semi-arid regions due to their lower energy consumption, reduced investment costs, and high water quality.

Thus, evaporation suppression techniques are considered promising for reducing salinity in surface water bodies, such as *barreiros* (a form of water storage used by rural populations in the Brazilian semi-arid region). However, further quantitative studies are needed to assess their direct impact on water salinity reduction, as well as a more detailed analysis of salt transport to groundwater under these conditions.

Desalination techniques have effectively reduced salinity in brackish groundwater extracted from wells drilled in crystalline aquifers. However, more significant investments and public policies are required to improve the implementation, maintenance, and management of desalination systems, particularly to serve low-income populations in dispersed communities of the semi-arid region through community wells.

Therefore, it can be concluded that, when combined, evaporation suppression and aquifer desalination techniques are effective and highly relevant processes for reducing water salinity in supplies intended for dispersed communities.

Acknowledgment

The authors acknowledge FACEPE for the financial support provided for the development of the UNIVERSITAS project (APQ-0300-5.03/17), as well as CAPES for the financial support through a scholarship grant.

References

ALHASSOUN, S.A.; ALSHAIKH, A.M.A.; ALREHAILI, A.M.; MISBAHUDDIN, M. Effectiveness of using palm fronds in reducing water evaporation. *Canadian Journal of Civil Engineering*, v. 38, 1170–1174, 2011.

Al-KARAGHOULI, A.; RENNE, D.; KAZMERSKI, L.L. Solar and wind opportunities for water desalination in the Arab regions. *Renewable and Sustainable Energy Reviews*, v. 13, 2397–2407, 2009.

ALVAREZ, V.M.; BAILLE, A.; MARTÍNEZ, J.M.M.; GONZÁLEZ-REAL, M.M. Efficiency of shading materials in reducing evaporation from free water surfaces. *Agricultural Water Management*, v. 84, 229–239, 2006.

AMATO, F.; PACE, F.; VERGNANO, A.; COMINA, C. TDEM prospections for inland groundwater exploration in semiarid climate, Island of Fogo, Cape Verde. *Journal of Applied Geophysics*, v. 184, 104242, 2021.

BEJJANKI, D.; MUTHUKUMAR, K.; RADHAKRISHNAN, T.K.; ALAGARSAMY, A.; PUGAZHENDHI, A.; NAINA MOHAMED, S. Simultaneous bioelectricity generation and water desalination using Oscillatoria sp. as biocatalyst in photosynthetic microbial desalination cell. *Science of the Total Environment*, v. 754, 2021.

BLAZYTE, A.; ALAYANDE, A.B.; NGUYEN, T.T.; ADHA, R.S.; JANG, J.; AUNG, M.M.; KIM, I.S. Effect of size fractioned alginate-based transparent exopolymer particles on initial bacterial adhesion of forward osmosis membrane support layer. *Journal of Industrial and Engineering Chemistry*, v. 94, 408–418, 2021.

CARTWRIGHT, I.; GILFEDDER, B.; HOFMANN, H. Chloride imbalance in a catchment undergoing hydrological change: Upper Barwon River, southeast Australia. *Applied Geochemistry*, v. 31, 187–198, 2013.

CHEN, J.P.; CHIAN, E.S.K.; SHENG, P.; NANAYAKKARA, K.G.N.; WANG, L.K. Desalination of Seawater by Reverse Osmosis. In: WANG, LAWRENCE K.; CHEN, JIAPING PAUL; HUNG, YUNG-TSE; SHAMMAS, NAZIH K. *Membrane and Desalination Technologies*, v. 13, 2011. p. 559-601.

CIRILO, J.A. Políticas públicas de recursos hídricos para o semi-árido. *Estudos Avançados,* v. 22, 61–82, 2008.

DINCER, S.; DINCER, I. Comparative evaluation of possible desalination options with various nuclear power plants. *In: Exergetic*, *Energetic and Environmental Dimensions*, 2018.

GALLEGO-ELVIRA, B.; BAILLE, A.; MARTIN-GORRIZ, B.; MAESTRE-VALERO, J.F.; MARTÍNEZ-ALVAREZ, V. Energy balance and evaporation loss of an irrigation reservoir equipped with a suspended cover in a semiarid climate (south-eastern Spain). *Hydrological Processes*, v. 25, 1694–1703, 2011.

GALLEGO-ELVIRA, B.; MARTÍNEZ-ALVAREZ, V.; PITTAWAY, P.; BRINK, G.; MARTÍN-GORRIZ, B. Impact of micrometeorological conditions on the efficiency of artificial monolayers in reducing evaporation. *Water Resources Management*, v. 27, 2251–2266, 2013.

GAMBOA, C.; GODFREY, L.; HERRERA, C.; CUSTODIO, E.; SOLER, A. The origin of solutes in groundwater in a hyper-arid environment: A chemical and multi-isotope approach in the Atacama Desert, Chile. *Science of the Total Environment*, v. 690, 329–351, 2019.

GHAFFOUR, N.; MISSIMER, T.M.; AMY, G.L. Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. *Desalination*, v. 309, 197–207, 2013.

HAAS, J.; KHALIGHI, J.; DE LA FUENTE, A.; GERBERSDORF, S.U.; NOWAK, W.; CHEN, P.J. Floating photovoltaic plants: Ecological impacts versus hydropower operation flexibility. *Energy Conversion and Management*, v. 206, 2020.

HAGHIGHI, E.; MADANI, K.; HOEKSTRA, A.Y. The water footprint of water conservation using shade balls in California. *Nature Sustainability*, v. 1, 358–360, 2018.

HAN, D.; SONG, X.; CURRELL, M.J.; CAO, G.; ZHANG, Y.; KANG, Y. A survey of groundwater levels and hydrogeochemistry in irrigated fields in the Karamay Agricultural Development Area, northwest China: Implications for soil and groundwater salinity resulting from surface water transfer for irrigation. *Journal of Hydrology*, v. 405, 217–234, 2011.

HAN, K.W.; SHI, K. BIN; YAN, X.J.; CHENG, Y.Y. Water savings efficiency of counterweighted spheres covering a plain reservoir in an arid area. *Water Resources Management*, v. 33, 1867–1880, 2019.

HAN, K.W.; SHI, K. BIN, YAN, X.J. Evaporation loss and energy balance of agricultural reservoirs covered with counterweighted spheres in arid region. *Agricultural Water Management*, v. 238, 106227, 2020.

HAO, GUO-CHEN; SHI, KE-BIN; HAN, KE-WU. Evaluating the impact of floating spheres on evaporation reduction and water salinity control in reservoirs. *Agricultural Water Management,* v. 312, 2025.

HASSAN, M.M.; PEIRSON, W.L.; NEYLAND, B.M.; FIDDIS, N.M.Q. Evaporation mitigation using floating modular devices. *Journal of Hydrology*., v. 530, 742–750. 2015.

HELFER, F.; ANDUTTA, F.P.; LOUZADA, J.A.; ZHANG, H.; LEMCKERT, C. Artificial destratification for reducing reservoir water evaporation: Is it effective? *Lakes and Reservoirs: Research and Management*, v. 23, 333–350, 2018.

JAT, M.L.; SAMMAURIA, R.; MARUTHISANKAR, G.R.; KOTHARI, A.K.; SHARMA, S.K.; BALYAN, J.K.; MISHRA, P.K. Assessment of seasonal efficacy of different evaporation retardants in semi-arid tropics. *J. Agrometeorol,* v. 12, 225–228, 2010.

KOUADIO, K.L.; XU, Y.; LIU, C.M., BOUKHALFA, Z. Two-dimensional inversion of CSAMT data and three-dimensional geological mapping for groundwater exploration in Tongkeng Area, Hunan Province, China. *Journal of Applied Geophysics,* v. 183, 2020.

KREIS, M.; TAUPIN, J.D.; PATRIS, N.; MARTINS, E.S.P.R. Isotopic characterisation and dating of groundwater recharge mechanisms in crystalline fractured aquifers: example of the semi-arid Banabuiú watershed (Brazil). *Isotopes in Environmental and Health Studies,* v. 56, 418–430, 2020.

LEE, H.J.; SARFERT, F.; STRATHMANN, H.; MOON, S.H. Designing of an electrodialysis desalination plant. *Desalination,* v. 142, 267–286, 2002.

LIU, L.; CHENG, Q. Mass transfer characteristic research on electrodialysis for desalination and regeneration of solution: A comprehensive review. *Renewable and Sustainable Energy Reviews,* v. 134, 2020.

LIU, Y.; JIN, M.; WANG, J. Insights into groundwater salinization from hydrogeochemical and isotopic evidence in an arid inland basin. *Hydrological Processes,* v. 32, 3108–3127, 2018.

LOPES, P.C.M.; DE ANDRADE NETO, S.; ALVES CASTELO BRANCO, D.; VASCONCELOS DE FREITAS, M.A.; DA SILVA FIDELIS, N. Water-energy nexus: Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil. *Journal of Cleaner Production,* v. 273, 2020.

MARTINEZ-ALVAREZ, V.; MAESTRE-VALERO, J.F.; MARTIN-GORRIZ, B.; GALLEGO-ELVIRA, B. Experimental assessment of shade-cloth covers on agricultural reservoirs for irrigation in south-eastern Spain. *Spanish Journal of Agricultural Research,* v. 8, 122–133, 2010.

MOCOCK, J.F.B.; PESSÔA, C.N.; MONTEIRO, Â.T. DA S.; TORRES, A.S.C.G.; RABBANI, E.R.K. *Estudo comparativo entre os principais métodos de dessalinização de águas subterrâneas: Revisão de literatura*. Escola Politécnica Pernambuco, 2015.

MOHARRAM, N.A.; BAYOUMI, S.; HANAFY, A.A.; EL-MAGHLANY, W.M. Hybrid desalination and power generation plant utilizing multi-stage flash and reverse osmosis driven by parabolic trough collectors. *Case Studies in Thermal Engineering,* v. 23, 100807, 2021.

MONDAL, N.C.; SINGH, V.P. Hydrochemical analysis of salinization for a tannery belt in Southern India. *Journal of Hydrology.,* v. 405, 235–247, 2011.

MONTENEGRO, A.A.A.; MONTENEGRO, S.M.G.L. Olhares sobre as políticas públicas de recursos hídricos para o semiárido, In: GHEYI, HANS RAJ; PAZ, VITAL PEDRO DA SILVA; MEDEIRO, SALOMÃO DE SOUSA; GALVÃO, CARLOS DE OLIVEIRA (ed.). *Recursos Hídricos em Regiões Semiáridas: Estudos e Aplicações*. Campina Grande, PB: Instituto Nacional do Semiárido, Cruz das Almas, BA: Universidade Federal do Recôncavo da Bahia, 2012.

MOURA, J.P.; MONTEIRO, G.S.; SILVA, J.N.; F.A.; P.; FRANÇA, K.P. Aplicações do processo de osmose reversa para o aproveitamento de água salobra do semi-árido nordestino. *Revista Águas Subterrâneas*, 2008.

MOZAFARI, A.; MANSOURI, B.; CHINI, S.F. Effect of Wind Flow and Solar Radiation on Functionality of Water Evaporation Suppression Monolayers. *Water Resources Management,* v. 33, 3513–3522, 2019.

NAPOLI, C.; RIOUX, B. Evaluating the economic viability of solar-powered desalination: Saudi Arabia as a case study. *International Journal of Water Resources Development,* v. 32, 412–427, 2016.

ORIBI, M.O.; ABDULKAREEM, A.K. Scenarios to reduce evaporation from class A evaporation pan by using windbreaks. *Scientific Review Engineering and Environmental Sciences,* v. 29, 343–354, 2020.

OYEYEMI, K.D.; AIZEBEOKHAI, A.P.; OLOFINNADE, O.M.; SANUADE, O.A. Geoelectrical investigations for groundwater exploration in crystalline basement terrain, sw nigeria: Implications for groundwater resources sustainability. *International Journal of Civil Engineering and Technology,* v. 9, 765–772, 2018.

PBMC - Painel Brasileiro de Mudanças Climáticas, 2014. *Impactos, Vulnerabilidades e Adaptação: Primeiro relatório de avaliação nacional*. 2014.

PEREIRA, L.; SANTIAGO, M.M.F.; FRISCHKORN, H.; ARAÚJO, J.C.; LIMA, J.O.G. A salinidade das águas superficiais e subterrâneas na bacia da Gameleira, Município de Aiuaba/CE. *Águas Subterrâneas,* v. 20, 9–18, 2006.

PIMENTEL DA SILVA, G.D.; SHARQAWY, M.H. Techno-economic analysis of low impact solar brackish water desalination system in the Brazilian Semiarid region. *Journal of Cleaner Production,* v. 248, 2020.

RAJMOHAN, N.; AL-FUTAISI, A.; AL-TOUQI, S. Geochemical process regulating groundwater quality in a coastal region with complex contamination sources: Barka, Sultanate of Oman. *Environmental Earth Sciences,* v. 59, 385–398, 2009.

RAJMOHAN, N.; MASOUD, M.H.Z.; NIYAZI, B.A.M. *Impact of evaporation on groundwater salinity in the arid coastal aquifer, Western Saudi Arabia*. Catena, v. 196, 2021.

SAHU, A.; YADAV, N.; SUDHAKAR, K. Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews,* v. 66, 815–824, 2016.

SALES, M.L.S.; CAMPOS, K.C.; CAMPOS, R.T.; GUIMARÃES, J.W.A. Avaliação financeira das ações de captação, acumulação e suprimento de água no estado de Ceará. *Revista Econômica do Nordeste*, v. 48, 139–154, 2017.

SANTOS, M.; FREIRE, C.; SOUZA, V. Comportamento do fluxo subterrâneo em um aquífero aluvial no semi-árido alagoano. *In: Anais* do XVIII Simpósio Brasileiro Recursos Hídricos, 1–13, 2009.

SARAI ATAB, M.; SMALLBONE, A.J.; ROSKILLY, A.P. An operational and economic study of a reverse osmosis desalination system for potable water and land irrigation. *Desalination,* v. 397, 174–184, 2016.

SILVA, P.C.G.; MOURA, M.S.B.; KIILL, L.H.P.; BRITO, L.T.L.; PEREIRA, L.A.; SÁ, I.B.; CORREIA, R.C.; TEIXEIRA, A.H.C.; CUNHA, T.J.F.; GUIMARÃES-FILHO, C.G. Caracterização do Semiárido brasileiro: fatores naturais e humanos. In: SA, I. B.; SILVA, P. C. G. da. (ed.). *Semiárido brasileiro: pesquisa, desenvolvimento e inovação.* Petrolina: Embrapa Semiárido, 2010. p. 18-48.

SILVA, T. L. *Uso e eficiência de dessalinizadores para o abastecimento de água de população difusa do semiárido de Pernambuco*. 2022. Dissertação (Mestrado – Construção Civil) - Escola Politécnica de Pernambuco - Universidade de Pernambuco, Recife, 2022.

SIMON, K.; SHANBHAG, R.; SLOCUM, A.H. Reducing evaporative water losses from irrigation ponds through the reuse of polyethylene terephthalate bottles. *Journal of Irrigation and Drainage Engineering,* v. 142, 2016.

SOVOCOOL, K. Erratum: Testing an innovative evaporative suppressant for reducing losses from lakes. *J. Am. Water Works Assoc.,* v. 106, 41-50, 2014.

STEIN, S.; SIVAN, O.; YECHIELI, Y.; KASHER, R. Redox condition of saline groundwater from coastal aquifers influences reverse osmosis desalination process. *Water Research,* v. 188, 2021.

STOJSAVLJEVIC JR, T.G. *Mathematical Modeling and Analysis of a Phytoplankton Competition Model Incorporating Preferential Nutrient Uptake*. 2019. Dissertation - University of Wisconsin-Milwaukee, Milwaukee, 2019.

STRATHMANN, H. Electrodialysis, a mature technology with a multitude of new applications. *Desalination,* v. 264, 268–288, 2010.

SUN, Z.; MA, R.; WANG, Y.; HU, Y.; SUN, L. Hydrogeological and hydrogeochemical control of groundwater salinity in an arid inland basin: Dunhuang Basin, northwestern China. *Hydrological Processes,* v. 30, 1884–1902, 2016.

TABOADA, M.E.; CÁCERES, L.; GRABER, T.A.; GALLEGUILLOS, H.R.; CABEZA, L.F.; ROJAS, R. Solar water heating system and photovoltaic floating cover to reduce evaporation: Experimental results and modeling. *Renew Energy,* v. 105, 601–615, 2017.

TAN, S.P.V.; BAUTISTA, A.T.; MENDOZA, N.D.S.; RACADIO, C.D.T.; PUTHENPUREKAL, M.; RESURRECCION, A.C.; MATSUZAKI, H. *I*odine-129 for determining the origin of salinity in groundwater in Pampanga, Philippines. *Journal of Environmental Radioactivity,* v. 218, 106239, 2020.

WALHA, K.; AMAR, R.B., FIRDAOUS, L.; QUÉMÉNEUR, F.; JAOUEN, P. Brackish groundwater treatment by nanofiltration, reverse osmosis and electrodialysis in Tunisia: performance and cost comparison. *Desalination,* v. 207, 95–106, 2007.

WRIGHT, N.C.; SHAH, S.R.; AMROSE, S.E.; WINTER, A.G. A robust model of brackish water electrodialysis desalination with experimental comparison at different size scales. Desalination 443, 27–43. 2018.

YANG, H.; KAGABU, M.; OKUMURA, A.; SHIMADA, J.; SHIBATA, T. Processos hidrogeoquímicos e efeitos de longo prazo da elevação do nível do mar em uma ilha elevada de atol de Minami-Daito, Japão. *Journal of Hydrology: Regional Studies,* v. 31, 1–12, 2020.

ZIADI, A.; HARIGA, N.T.; TARHOUNI, J. Mineralization and pollution sources in the coastal aquifer of Lebna, Cap Bon, Tunisia. *Journal of African Earth Sciences,* v. 151, 391–402, 2019.