

RESEARCH ARTICLE

ENVIRONMENTAL SUSTAINABILITY OF DESALINATION: A CRITICAL REVIEW OF BRINE TREATMENT CHALLENGES AND MITIGATION STRATEGIES

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ABSTRACT

Desalination has become a vital means of producing drinkable water in areas of the world where there is a shortage of water, giving millions of people access to clean water. However, the long-term viability of desalination is questioned due to its effects on the environment, especially the concentrated brine it produces. This review examines the environmental impacts of desalination and brine treatment, with a particular focus on the challenges and mitigation strategies for minimising their ecological footprint. The production of high-salinity brine, often containing pollutants, represents a significant threat to marine ecosystems. This is due to the increased salinity levels, habitat degradation and disruption of marine biodiversity that it causes. Furthermore, desalination processes consume a considerable amount of energy, contributing to greenhouse gas emissions, and often involve the use of chemicals that can have adverse environmental consequences. The review discusses a range of mitigation measures, including advanced brine treatment technologies, energy efficiency improvements, and the development of sustainable desalination practices. By highlighting the challenges and opportunities for minimising environmental impacts, this review emphasises the need for a holistic approach to ensure the environmentally responsible implementation of desalination as a water management strategy.

KEYWORDS

Desalination, Brine Disposal, Environmental Impacts, Membrane-based Technologies, Sustainability.

1. INTRODUCTION

Water is a vital component of life on Earth (Singh, 2024), yet the planet's freshwater resources are scarce in comparison to the vast quantities of saltwater (Ismail, et al., 2024). As the global population continues to expand and water consumption increases, it becomes imperative to develop innovative solutions to ensure an adequate supply of clean water for drinking, agriculture, and industry. Desalination has emerged as a promising solution (Azdem et al., 2024), offering a means of transforming saltwater into freshwater (Fahdi et al., 2024). This technology is currently in use in over 140 countries, providing drinking water to millions of people (Azdem et al., 2024). Although desalination is frequently regarded as an environmentally benign solution (Lin et al., 2023) it is important to acknowledge the potential environmental implications associated with any industrial process. One significant concern is the generation of brine, a highly concentrated salt solution (Al-Amoudi et al., 2023) that remains as a by-product of the desalination process. Brine is considerably more saline than seawater and may contain harmful chemicals used in the desalination plant (Azdem et al., 2024; Basheir et al., 2024), which could have a detrimental impact on marine life and coastal ecosystems (Sirota et al., 2024). At present, most brine from desalination plants is released directly into the ocean (Porto Pereira et al., 2024), raising significant concerns regarding its effects on marine ecosystems. Additionally, desalination is a highly energy-demanding process, predominantly powered by fossil fuels (Mabrouki et al., 2022). This reliance on non-renewable energy sources exacerbates greenhouse gas emissions and atmospheric pollution, further intensifying the environmental footprint of desalination activities. The

environmental effects of desalination can be observed during both the construction of the plants and their ongoing operation (Bencheikh et al., 2020). The specific impacts of desalination may vary depending on the water source and the location of the plant, but the need for careful management and mitigation strategies remains constant.

A number of reviews on the subject have been published to date by (Soliman et al., 2021) which explore the potential environmental effects of desalination facilities on coastal zone ecosystems. A further review paper (Sirota et al., 2024) examined the environmental impact of brine discharge from desalination plants on benthic ecosystems. Furthermore, (Abdul Ghani et al., 2021) conducted an investigation into the environmental impact of the Malaysian seawater reverse osmosis (SWRO) plant. More recently, (Bencheikh et al., 2020) studied the negative impacts of desalination brine on marine flora and fauna. Existing reviews often overlook the latest advancements in desalination technology, including both commercial and emerging innovations that can be used to treat brine and recover valuable resources like freshwater and salts. Additionally, recent and cutting-edge mitigation strategies are often not fully explored. This review aims to bridge this gap by (1) analysing and evaluating the potential environmental impacts of desalination technologies, (2) ranging from brackish water to brine treatment. We will (3) explore the current state of desalination technologies and then delve into their environmental impacts, (4) highlighting mitigation measures that can help minimize these risks. Finally, we will (5) discuss our findings and offer perspectives on future directions for the sustainable development of desalination. We

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utilized the following keywords to conduct a comprehensive search across various databases including Google Scholar, SCOPUS, and Science Direct: "The environmental impact of desalination", "discharged desalination brine", "Environmental Impacts and Brine Management", "environmental impact assessment of desalination plants", and "Characteristics of desalination brine". Our search yielded a total of 1081 publications on the subject (471 from Google Scholar, 314 from SCOPUS, and 296 from Science Direct). To ensure relevance, we focused on peer-reviewed articles published within the last 20 years (2003-2023), available in full-text and written in English, and removed duplicates. This process left us with 215 unique papers for detailed analysis in our review.

2. CONVENTIONAL DESALINATION TECHNOLOGIES

2.1 Global Trends in Desalination Technologies and Capacities

Desalination technologies have evolved significantly and can be divided into two categories (Shalaby et al., 2024) based on their operating principles as shown in Fig.1: thermal-based and membrane-based. Thermal-based approaches use heat to achieve separation by distillation or evaporation, mirroring natural water cycles where saline solutions are evaporated and condensed to produce fresh water. Key thermal desalination technologies, such as Multi-Effect Distillation (MED) and Multi-Stage Flash Distillation (MSF), are widely recognized for their efficiency in large-scale applications (Tareemi and Sharshir, 2023). On the other hand, membrane-based technologies function without a phase change by utilizing semi-permeable membranes that permit water molecules to pass while blocking salts and other impurities. These processes rely on electrical energy to create the pressure differences required for separation. The main membrane-based techniques include reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED) and electro dialysis reversal (EDR), each of which uses different filtration and ion exchange mechanisms to purify water (Altiok et al., 2024).

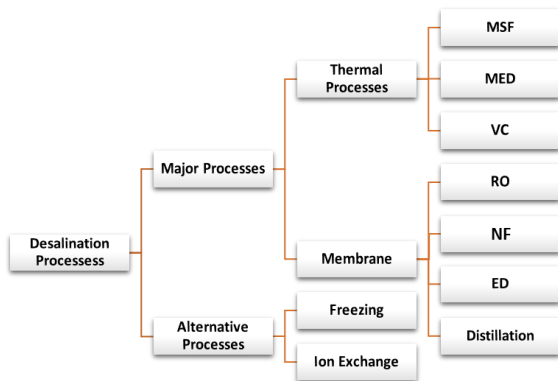


Figure 1: The classification of desalination technologies.

Currently, thermal distillation processes account for approximately 35% of desalination, while reverse osmosis dominates with a share of 63% (Farid et al., 2024), underscoring their key role in meeting global freshwater needs. The total installed desalination capacity worldwide is about 115 million cubic metres per day (Mm^3/d) (Bencheikh et al., 2020), of which reverse osmosis (RO) technology accounts for about 88 Mm^3/d . Recent literature (Bencheikh et al., 2020; Farid et al., 2024) highlights RO as the most important and widely used desalination method, used not only for saline water treatment but also for industrial and potable water production (Bhandari et al., 2023). Fig.2 shows the outlines the global use of different desalination methods along with their respective production capacities.

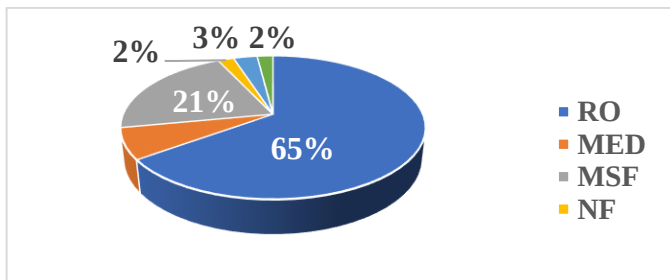


Figure 2: The global utilization of desalination technologies (Al-Rawajfeh et al., 2023; Benchrifia et al., 2023).

Desalination historically demands substantial energy inputs (Mahmoudi et al., 2023). primarily from fossil fuels, for either thermal or electrical

power (Table 1). This approach incurs high operational expenses and contributes to the release of harmful air pollutants and greenhouse gases into the atmosphere (Wang and Azam 2024).

	MSF	MED	VC	RO	ED
Electrical energy Consumption (kWh/m^3)	4.2-6.1	1.7-2.4	6-11.5	3.2-7.1	2.3-5.8
Thermal energy Consumption (MJ/m^3)	250-300	150-220	220-240	-	-
Electrical Equivalent for thermal Energy (kWh/m^3)	9.7-20	5.3-9	-	-	-
Total Equivalent Energy Consumption (kWh/m^3)	13-25	6-11.5	7.3-11	3.3-7	2.6-5.5

2.2 Desalination Technologies In North African Countries

Desalination technologies have been integral to addressing water scarcity in North Africa since the early 1950s (Fattah et al., 2022), albeit in modest scales and capacities initially. The transformative phase commenced in the mid-1970s, particularly in Libya and Algeria, where the burgeoning oil industry necessitated reliable water sources. Rapid advancements in Reverse Osmosis (RO) technology have propelled its widespread adoption across the region. RO stands out as the preferred method due to the region's favorable water salinity levels (Al-Addous et al., 2024), making it both economically viable and technically feasible for large-scale desalination projects (Sarmiento Barrios et al., 2024) (Fig.3).

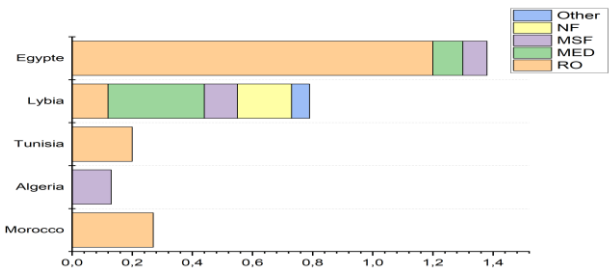


Figure 3: Desalination Capacities (Mm^3/day) in North African Nations (Sarmiento Barrios et al., 2024) .

3. CONVENTIONAL DESALINATION TECHNOLOGIES

The discharge of brine is recognized as the primary vehicle for environmental impacts (Tu et al., 2024), transporting nearly all liquid waste generated in desalination processes (Akinpelu, 2023). This includes chemicals used in pre-treatment, corrosion by-products, filter backwash, and concentrated brine from reverse osmosis (RO) desalination (Fattah et al., 2023). This part examines various environmental impacts linked to brine disposal in membrane desalination, highlighting its significance as a major environmental concern.

3.1 Environmental Challenges and Impacts of Membrane-Based Desalination Processes

One of the most significant challenges currently facing desalination technology is the need to mitigate its environmental impact. The implementation of desalination processes may result in a range of direct and indirect environmental consequences (Nasrollahi et al., 2023). The environmental impact of membrane-based desalination is influenced by several key components, including the intake of feed water, brine discharge, the desalination mechanism itself, pre-treatment of the feed water, and the energy demands associated with the process (Wang et al., 2024). In particular, brine discharge has been identified as a significant source of environmental impact (Azdem et al., 2024 ; Sola et al., 2024), due to the corrosive by-products, filter backwash and chemicals used in pre-treatment that it contains.

3.2 The Effects of Brine Disposal from Membrane-Based Desalination

Brine discharge from desalination operations is widely recognized as the

primary waste product in terms of both volume and composition (Rivero-Falcón et al., 2023). The environmental impacts (EIs) of brine on marine ecosystems and aquatic organisms are largely driven by factors such as increased salinity, elevated temperature, pH levels, heavy metal content, and residual chemicals (Tu et al., 2024). Numerous EIs studies focus on analyzing brine properties at the point of discharge and after initial mixing with seawater in the mixing zone (Sun et al., 2023; Azdem et al., 2024), in order to better evaluate its potential effects. Recently, (Sirota et al., 2024) conducted a thorough study examining the specific impacts of seawater desalination on marine ecosystems and aquatic organisms. (Benchrifa et al., 2022) work consolidates various findings from diverse sources, including scientific publications, environmental monitoring data, and environmental impact assessments (EIAs). The focus of this research is on the effects of desalination has on ocean ecosystems, particularly with respect to water intake and brine discharge systems. However, the study is limited to marine environmental impacts, excluding other critical aspects like emissions. For a comprehensive assessment of desalination's environmental consequences, it is essential to consider all stages of the process. This review takes such an approach, addressing these broader issues. Figure 4 summarizes the main physical, chemical, and biological impacts of brine discharge on the marine environment in Seawater Reverse Osmosis (SWRO) desalination.

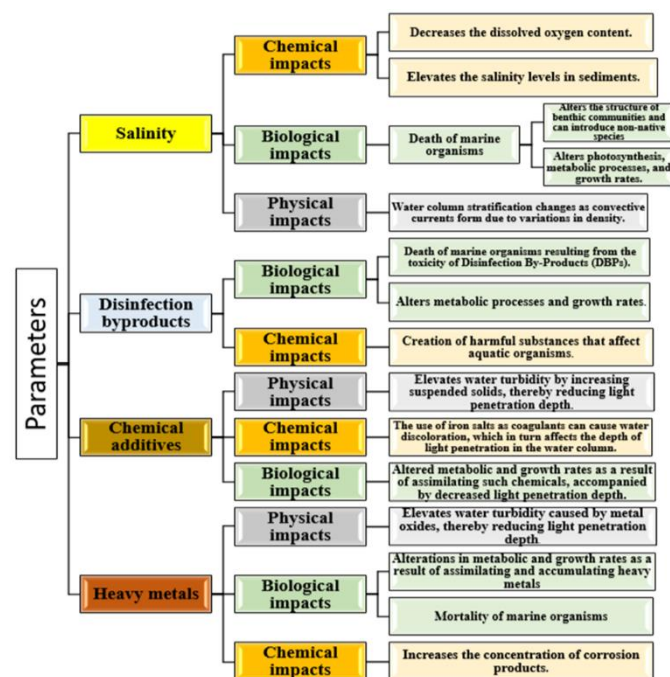


Figure 4: Environmental Impacts of Desalination Brine: Physical, Chemical, and Biological Effects.

3.3 Greenhouse Gas (GHG) Emissions

Desalination is a highly energy-demanding process (Mabrouki et al., 2022), largely reliant on non-renewable fossil fuels, which contribute to climate change (Shahid et al., 2023). This raises significant concerns about the environmental impact of desalination plants, particularly in terms of energy consumption and greenhouse gas (GHG) emissions. The primary challenge is to reduce the overall energy demand of these facilities, while the second is to transition towards renewable energy sources to lower GHG emissions. Presently, many desalination plants still rely heavily on fossil fuels, which release pollutants such as CO, NO, SO, and particulate matter (PM10) into the atmosphere. Figure 5 illustrates the GHG emissions associated with seawater reverse osmosis (SWRO) desalination. According to (Xue et al., 2023). SWRO plants powered by natural gas produce roughly 2.75, 2.15, and 1.65 kg-CO₂/m³ of water for the steam cycle (Khouya, 2023), internal combustion engine, and combined cycle, respectively. (Bencheikh et al., 2020) estimate that these facilities generate around 1.75 kg-CO₂/m³ of water based on their global warming potential. Regarding acidification, SO₂ emissions were estimated at about 22 g-SO₂/m³. Additionally, the carbon footprint of an SWRO plant with a daily production capacity of 0.65 MCM was estimated to range between 2.3 and 2.5 kg-CO₂/m³. In a larger study involving 18 desalination plants combining SWRO and brackish water reverse osmosis (BWRO) systems

with a combined capacity of 1.600 MCM/day, the total annual carbon emissions were estimated to be approximately 1,150 Kt CO₂, equating to about 1.80 kg-CO₂/m³.

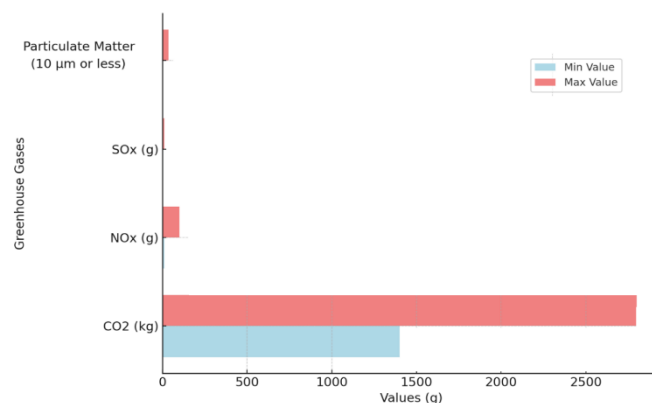


Figure 5: Greenhouse Gas Emissions from a Seawater Reverse Osmosis plant (Ai et al., 2023).

3.4 Environmental Effects of Brine Disposal from Thermal Desalination Processes

Thermal desalination systems, such as Multi-Stage Flash (MSF), typically require a much larger volume of input water to produce a specific amount of freshwater due to their lower recovery rates when compared to membrane-based techniques (Tareemi and Sharshir, 2023). As noted by (Bencheikh et al., 2020), MSF plants have an input-to-output ratio ranging between 9 and 19, with approximately 65% of the intake water being used for cooling purposes. Similarly, Multi-Effect Distillation (MED) systems function in a comparable manner but require less water for cooling (Dashputre et al., 2023). This leads to challenges like higher seawater usage and the need for larger infrastructure. Furthermore, these systems can adversely affect marine ecosystems by increasing the potential for water contamination and trapping marine life within the desalination process.

The environmental impacts (EIs) linked to brine disposal from thermal desalination processes largely mirror those seen in membrane-based systems, though some important differences exist (Dashputre et al., 2023). Key distinctions arise in factors such as brine temperature, flow rate, and salinity. Because thermal desalination systems tend to have lower recovery rates and require cooling, the brine discharge flow rate in membrane-based systems can be about three to five times higher than in thermal systems for comparable production levels (Ibrahim et al., 2023). In terms of salinity, brine from thermal desalination usually ranges between 32 g/L and 45 g/L (Al-Amoudi et al., 2023) which is generally lower than what is observed in Seawater Reverse Osmosis (SWRO) systems. However, the brine released from thermal processes is typically around 5 – 12°C warmer than the surrounding seawater (Ibrahim et al., 2023). These factors play a significant role in shaping the environmental impacts of brine discharge from thermal desalination systems. The release of brine into marine environments raises the temperature of the surrounding water due to the elevated temperature of the discharged brine (Liu et al., 2023). This thermal increase, combined with higher salinity levels, reduces dissolved oxygen in the water, which can result in increased mortality rates among marine organisms (Sirota et al., 2024), often caused by thermal shock. Furthermore, chemicals used during the pretreatment stage, such as corrosion inhibitors, antifoaming agents, antiscalants, residual biocides, and trace metals, are released into the ocean, potentially harming marine ecosystems and affecting sediment health (Bencheikh et al., 2020). Although these chemicals are essential for the smooth operation of desalination plants and maintaining water quality, they also present significant environmental challenges. (Poirier et al., 2023; Mehtari et al., 2023) found traces of these chemicals in the effluent from Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF) desalination plants, indicating their presence in discharged waters.

3.5 Environmental Impacts and Efficiency of Hybrid Desalination Systems

Hybrid desalination systems integrate both membrane-based and thermal-based processes (Gohil et al., 2023), each contributing unique environmental impacts. Consequently, the environmental effects (EIs) of hybrid systems are typically the sum of the impacts from each individual process (Yazdani et al., 2023). For instance, Electrodialysis (ED) and Electrodialysis Reversal (EDR) systems employ electrically-driven membranes rather than conventional hydraulic pressure (Vinothkumar et al., 2023), showcasing how various technologies are combined within

hybrid systems. Given the well-documented environmental effects of both membrane and thermal desalination techniques, assessing the EIs of hybrid systems is relatively straightforward (Bencheikh et al., 2020). These impacts are largely determined by three factors: (1) the type of hybridization, whether heterogeneous or homogeneous; (2) the system's complexity, which can range from bi-hybrid to tri-hybrid configurations; and (3) the specific desalination technologies used.

The primary objectives driving the development of hybrid systems cost reduction, increased efficiency, and enhanced productivity also align with environmental goals (Shalaby et al., 2023). Specifically:

(1) reducing energy consumption lowers greenhouse gas emissions, (2) improving recovery rates minimizes both water consumption and waste output, and (3) enhancing operational efficiency decreases the need for chemical pretreatment, thus reducing the release of harmful substances in brine discharge.

3.6 Environmental Considerations for Desalination Facility Intakes and Outfalls

Regardless of the desalination method used, all plants require intake and outfall systems, with their design and scale tailored to the specific technology in use (Elshaikh et al., 2024). Intakes fall into two main categories:

- open sea intakes, which include surface and submerged structures located just above the seabed (Nielsen et al., 2024).
- subsurface intakes, which use infiltration galleries or wells (de Miguel et al., 2023).

Similarly, outfall systems can be open or submerged. The selection of an intake and outfall system depends on factors such as plant size, desalination technique, local hydro-geomorphological features, and environmental impact (Aljohani et al., 2023), all of which significantly affect the overall costs. For instance, desalination plants near power stations often share intake and outfall configurations. The choice of intake system is especially important as it influences seawater pretreatment and overall plant efficiency (de Miguel et al., 2023). However, the introduction of these systems can disrupt marine ecosystems, making the reduction of environmental impact a critical consideration in their design and planning.

3.7 Sustainable Future Prospects for Desalination and Membrane Technologies

The future development of desalination processes should prioritize sustainability, particularly in membrane-based technologies (Abounahia et al., 2023). Integrating innovative scientific advancements with new system designs has the potential to yield global environmental benefits (Shalaby et al., 2023). To advance desalination technology in a more sustainable and eco-friendly direction, greater emphasis must be placed on green manufacturing processes. Achieving a circular economy in desalination requires the implementation of multiple interconnected, closed-loop systems, ensuring minimal waste and resource reuse. Designing desalination technologies with this in mind is crucial for a sustainable future.

4. CONCLUSION

Water is a vital resource for sustaining life on Earth, with less than 1% of the planet's water being suitable for drinking. In North African nations, particularly Morocco, desalination has emerged as a crucial solution to address water scarcity driven by arid climates and limited freshwater resources. Morocco has been increasingly relying on desalination to secure water supplies for domestic, agricultural, and industrial purposes, with large-scale projects like the Agadir desalination plant setting an example for sustainable water management in the region.

However, the environmental challenges associated with desalination, especially the discharge of concentrated brine, pose significant risks to marine ecosystems. The increase in salinity, along with chemical pollutants in brine, threatens marine biodiversity and disrupts coastal habitats. Additionally, the energy-intensive nature of desalination contributes to greenhouse gas emissions, further complicating environmental sustainability efforts. This study has critically reviewed the environmental impacts of desalination in North Africa, highlighting the need for effective mitigation strategies such as advanced brine treatment technologies and the adoption of renewable energy sources. While desalination plays an essential role in meeting water demands, particularly in regions like Morocco, addressing its environmental consequences is vital to ensure the long-term sustainability of water resources.

The key findings are as follows:

1. Desalination technologies, particularly reverse osmosis, dominate water production in North Africa due to the region's favorable water salinity levels.
2. Brine discharge remains a significant environmental challenge, requiring advanced treatment solutions to mitigate its impact on marine ecosystems.
3. A transition towards energy-efficient and renewable-powered desalination plants is essential for reducing the carbon footprint of water production in Morocco and other North African nations.
4. Hybrid systems combining multiple desalination methods show promise in improving recovery efficiency and reducing environmental harm.

In conclusion, while desalination offers a reliable solution to water scarcity in Morocco and North Africa, careful attention must be paid to minimizing its environmental footprint. Sustainable practices and innovative technologies will be crucial in ensuring the long-term viability of desalination as part of the region's water management strategy.

REFERENCE

- Abdul Ghani, L., Ali, N. A., Nazaran, I. S., and Hanafiah, M. M., 2021. Environmental performance of small-scale seawater reverse osmosis plant for rural area water supply », *Membranes*, vol. 11, no 1, 40, 2021.
- Abounahia, N. M., El-Sayed, A. M. A., Saleem, H., and Zaidi, S. J., 2023. Overview on the progress in produced water desalination by membrane-based technology, *Journal of Water Process Engineering*, vol. 51, p. 103479, févr. 2023, doi: 10.1016/j.jwpe.2022.103479.
- Ai, C., Zhao, L., Song, D., Han, M., Shan, Q., and Liu, S., 2023. Identifying greenhouse gas emission reduction potentials through large-scale photovoltaic-driven seawater desalination », *Science of The Total Environment*, vol. 857, p. 159402, janv. 2023, doi: 10.1016/j.scitotenv.2022.159402.
- Akinpelu, A. A., 2023. Chapter 23 - Brine waste management in desalination industry: a prospective wealth from waste, in *Innovation of Food Products in Halal Supply Chain Worldwide*, N. N. Ahmad Nizar, S. A. S. Zainal Abidin, et A. Bujang, Éd., Academic Press, 2023, p. 311-329. doi: 10.1016/B978-0-323-91662-2.00023-5.
- Al-Addous, M., Bdour, M., Rabaiah, S., Boubakri, A., Schweimanns, N., Barbana, N., and Wellmann, J., 2024. Innovations in Solar-Powered Desalination: A Comprehensive Review of Sustainable Solutions for Water Scarcity in the Middle East and North Africa (MENA) Region », *Water*, vol. 16, no 13, Art. no 13, janv. 2024, doi: 10.3390/w16131877.
- Al-Amoudi, A. S., Ihm, S., Farooque, A. M., Al-Waznani, E. S., and Voutchkov, N., 2023. Voutchkov, Dual brine concentration for the beneficial use of two concentrate streams from desalination plant - Concept proposal and pilot plant demonstration, *Desalination*, vol. 564, Pp. 116789, oct. 2023, doi: 10.1016/j.desal.2023.116789.
- Aljohani, N. S., Kavil, Y. N., Al-Farawati, R. K., Aljohani, N. H., Orif, M. I., Ghandourah, M. A., and Salam, M. A., 2023. The assessment of environmental parameter along the desalination plants in the Kingdom of Saudi Arabia », *Open Chemistry*, vol. 21, no 1, janv. 2023, doi: 10.1515/chem-2022-0274.
- Al-Rawajfeh, A. E., Alzalabieh, E., Al Bazed, G., Al-Mazaideh, G. M., and Shalayel, M. H. F., 2023. A review on harmful algae blooms in Arabian Gulf: causes and impacts on desalination plants », *Desalination and Water Treatment*, vol. 290, p. 46-55, avr. 2023, doi: 10.5004/dwt.2023.29482.
- Azdem, D., Mabrouki, J., Moufti, A., Hajjaji, S. E., 2024. Fatni, Present Situation and Environmental Impact of Seawater Desalination Plants in Morocco, in *Technical and Technological Solutions Towards a Sustainable Society and Circular Economy*, J. Mabrouki et A. Mourade, Éd., Cham: Springer Nature Switzerland, 2024, Pp. 581-592. doi: 10.1007/978-3-031-56292-1_46.
- Azdem, D., Mabrouki, J., and El Hajjaji, S., 2024. Methods and Technologies for the Treatment and Disposal of Brine in Seawater Desalination Plants; in *Advances in Environmental Engineering and Green Technologies*, J. Mabrouki et M. Azrour, Éd., IGI Global, 2024, Pp.

79-87. doi: 10.4018/979-8-3693-3807-0.ch007.

- Basheir, E., Makkawi, Y., and Masek, O., 2024. Management and potential application of desalination brine reject in CO₂ capture and catalytic conversion processes », *Journal of Water Process Engineering*, vol. 66, Pp. 105956, sept. 2024, doi: 10.1016/j.jwpe.2024.105956.
- Bencheikh, I., Mabrouki, J., Azoulay, K., Moufti, A., and El Hajjaji, S., 2020. Predictive analytics and optimization of wastewater treatment efficiency using statistic approach. In *Big Data and Networks Technologies 3* (pp. 310-319). Springer International Publishing.
- Bencheikh, I., Mabrouki, J., Azoulay, K., Moufti, A., and El Hajjaji, S., 2020. Consequences Of Brine Discharges From Seawater Desalination On The Marine Ecosystem, Case Study Of The Kahrama Station In The North West Of Algeria. *Applied Ecology and Environmental Research*, vol. 22, no 2, 2024.
- Benchrif, M., Elouardi, M., Fattah, G., Mabrouki, J., and Tadili, R., 2023. Identification, simulation and modeling of the main power losses of a photovoltaic installation and use of the internet of things to minimize system losses. In *Advanced technology for smart environment and energy* (pp. 49-60). Cham: Springer International Publishing.
- Benchrif, M., Mabrouki, J., and Tadili, R., 2022, November. Estimation of global irradiation on horizontal plane using artificial neural network. In *The International Conference on Artificial Intelligence and Smart Environment* (pp. 395-400). Cham: Springer International Publishing.
- Bhandari, M., Kharkwal, S., and Prajapati, S. K., 2023. Recycling drinking water RO reject for microalgae-mediated resource recovery », *Resources, Conservation and Recycling*, vol. 188, p. 106699, janv. 2023, doi: 10.1016/j.resconrec.2022.106699.
- Dashputre, A., Kaushik, A., Pal, A., Jariwala, D., Yadav, K., and Shah, M., 2023. Geothermal energy integrated multi-effect evaporator (MEE) and multi-effect distillation (MED)-based desalination systems: an ecofriendly and sustainable solutions », *Environ Sci Pollut Res*, vol. 30, no 26, p. 67941-67952, juin 2023, doi: 10.1007/s11356-023-26858-w.
- Dashputre, A., Kaushik, A., Pal, A., Jariwala, D., Yadav, K., and Shah, M., 2023. Techno-economic feasibility and environmental impact evaluation of a hybrid solar thermal membrane-based power desalination system », *Energy*, vol. 278, p. 127923, sept. 2023, doi: 10.1016/j.energy.2023.127923.
- de Miguel, E., Avila, D., and Marichal, G. N., 2023. Marichal Plasencia, The environmental impact of water intakes and discharges for desalination. 2023. doi: 10.1109/ICECCME57830.2023.10252182.
- E. Altio, A. Cihanoglu, E. Güler, et N. Kabay, « Chapter 5 - Ion exchange membranes in electrodialysis process for wastewater treatment », in *Current Trends and Future Developments on (Bio-) Membranes*, A. Basile et K. Ghazemzadeh, Éd., Elsevier, 2024, p. 123-156. doi: 10.1016/B978-0-323-88509-6.00005-8.
- Elshaikh, A., Elsheikh, E., and Mabrouki, J., 2024. Applications of Artificial Intelligence in Precision Irrigation. *Journal of Environmental and Earth Sciences* | Volume, 6(02).
- Fahdi, G., Azdem, D., Lamchaimech, A., Benrhanem, M., Mabrouki, J., El Hajjaji, S., 2024. Analysis Of The Impact Of Climate Change On Water Resources: Case Of The Tensift Basin (MOROCCO), *Water Conservation and Management*, vol. 8, no 4, Pp. 461-465, 2024, doi: 10.26480/wcm.04.2024.461.465.
- Farid, M. U., Kharraz, J. A., Sharma, S., Khan, R. J., Khanzada, N. K., Deka, B. J., ... and An, A. K., 2024. Technological advancements in water heating approaches for membrane distillation desalination process: From bulk to localized heating », *Desalination*, vol. 574, p. 117235, avr. 2024, doi: 10.1016/j.desal.2023.117235.
- Fattah, G., Elouardi, M., Benchrif, M., Ghrissi, F., and Mabrouki, J., 2023. Modeling of the coagulation system for treatment of real water rejects. In *Advanced technology for smart environment and energy* Pp. 161-171. Cham: Springer International Publishing.
- Fattah, G., Mabrouki, J., Ghrissi, F., Azrou, M., and Abrouki, Y., 2022. Multi-sensor system and internet of things (IoT) technologies for air pollution monitoring. In *Futuristic research trends and applications of Internet of Things* Pp. 101-116. CRC Press.
- Gohil, P. P., Desai, H., Kumar, A., and Kumar, R., 2023. Current Status and Advancement in Thermal and Membrane-Based Hybrid Seawater Desalination Technologies », *Water*, vol. 15, no 12, Art. no 12, janv. 2023, doi: 10.3390/w15122274.
- Ibrahim, M., Nawaz, M. H., Rout, P. R., Lim, J. W., Mainali, B., and Shahid, M. K., 2023. Advances in Produced Water Treatment Technologies: An In-Depth Exploration with an Emphasis on Membrane-Based Systems and Future Perspectives », *Water*, vol. 15, no 16, Art. no 16, janv. 2023, doi: 10.3390/w15162980.
- Ibrahim, M., Nawaz, M. H., Rout, P. R., Lim, J. W., Mainali, B., and Shahid, M. K., 2023. The Production Brine Water Problems And Resources. laurea, Politecnico di Torino, 2023. Consulté le: 1 octobre 2024. [En ligne]. Disponible sur: <https://webthesis.biblio.polito.it/26041/>
- Ismail, M., Pradhanang, S. M., Boving, T., Motta, S., McCarron, B., et al., 2024. Volk, Review of Modeling Approaches at the Freshwater and Saltwater interface in Coastal Aquifers , *Land*, vol. 13, no 8, Art. no 8, août 2024, doi: 10.3390/land13081332.
- Khouya, A., 2023. 4E assessment of a hybrid RO/MED-TVC desalination plant powered by CPV/T systems », *Energy Conversion and Management*, vol. 277, p. 116666, févr. 2023, doi: 10.1016/j.enconman.2023.116666.
- Lin, F., Wang, J., Nutakki, T. U. K., Ayadi, M., Ahmad, S. F., Muhammad, T., and Lui, C., 2023. Proposal, process development, and multi-aspect investigation of a novel environmentally friendly multigeneration process in arrangement with a sea water desalination unit , *Journal of Environmental Chemical Engineering*, vol. 11, no 6, Pp. 111392, déc. 2023, doi: 10.1016/j.jece.2023.111392.
- Liu, C., Lowenstein, T. K., Wang, A., Zheng, C., and Yu, J., 2023. Brine: Genesis and Sustainable Resource Recovery Worldwide, *Annual Review of Environment and Resources*, vol. 48, no Volume 48, 2023, p. 371-394, nov. 2023, doi: 10.1146/annurev-environ-112621-094745.
- M. Grzegorz, K. Wartalska, et B. Kaźmierczak, « Review of water treatment methods with a focus on energy consumption », *International Communications in Heat and Mass Transfer*, vol. 143, p. 106674, avr. 2023, doi: 10.1016/j.icheatmasstransfer.2023.106674.
- Mabrouki, J., Azrou, M., Boubekraoui, A., and El Hajjaji, S., 2022. Simulation and optimization of solar domestic hot water systems. *International Journal of Social Ecology and Sustainable Development (IJSESD)*, 13(1), Pp. 1-11.
- Mahmoudi, A., Bostani, M., Rashidi, S., and Valipour, M. S., 2023. Opportunities of desalination with renewable energy resources in Middle East countries », *Renewable and Sustainable Energy Reviews*, vol. 184, Pp. 113543, sept. 2023, doi: 10.1016/j.rser.2023.113543.
- Mehtari, N., Kahani, M., and Zamen, M., 2023. Energy, environmental, and economic analysis of a new configuration multi-stage flash distillation unit coupled with steam power plant », *Case Studies in Thermal Engineering*, vol. 50, . 103456, oct. 2023, doi: 10.1016/j.csite.2023.103456.
- Mohammed R. A. and Jm Alkhafaj, R., 2023. Review: Water Desalination Cost , *UTJES*, vol. 13, no 1, p. 1-10, déc. 2023, doi: 10.31663/tqujes13.1436(2023).
- Nasrollahi, M., Motevali, A., Banakar, A., and Montazeri, M., 2023. Montazeri, Comparison of environmental impact on various desalination technologies », *Desalination*, vol. 547, Pp. 116253, févr. 2023, doi: 10.1016/j.desal.2022.116253.
- Nielsen, K., Schlenk, D., Esbaugh, A., and Mondon, J., 2024. Potential Environmental Impacts of Coastal Desalination Intake Structures: Urgent Data Gaps and Policy Needs | *Environmental Science and Technology Letters* ». Consulté le: 1 octobre 2024. [En ligne]. Disponible sur: <https://pubs.acs.org/doi/abs/10.1021/acs.estlett.4c00228>
- Poirier, K., Lotfi, M., Garg, K., Patchigolla, K., Anthony, E. J., Faisal, N. H., ... & Al Mhanna, N., 2023. A comprehensive review of pre- and post-treatment approaches to achieve sustainable desalination for different water streams », *Desalination*, vol. 566, p. 116944, nov. 2023, doi: 10.1016/j.desal.2023.116944.

- Porto Pereira, S., Rodrigues, M. F., Rosman, P. C. C., Rosman, P., Bleninger, T., Lima Neto, I. E., and Sánchez Lizaso, J. L., 2024. A novel tool for modeling the near- and far-field dispersion of brine effluent from desalination plants, *Front. Mar. Sci.*, vol. 11, juill. 2024, doi: 10.3389/fmars.2024.1377252.
- Rivero-Falcón, Á., Peñate Suárez, B., and Melián-Martel, N., 2023. Brine Characterisation and Critical Analysis of Its Industrial Valorisation: A Case Study in the Canary Islands (Spain) », *Water*, vol. 15, no 8, Art. no 8, janv. 2023, doi: 10.3390/w15081600.
- Sarmiento Barrios, M. S., Haider, H., Chhipi-Shrestha, G. K., Kaur, M., Hewage, K., and Sadiq, R., 2024. Review of the water-energy-carbon nexus in small and medium drinking water systems: challenges and opportunities », *Environ. Rev.*, juill. 2024, doi: 10.1139/er-2023-0147.
- Shahid, M. K., Mainali, B., Rout, P. R., Lim, J. W., Aslam, M., Al-Rawajfeh, A. E., and Choi, Y., 2023. A Review of Membrane-Based Desalination Systems Powered by Renewable Energy Sources », *Water*, vol. 15, no 3, Art. no 3, janv. 2023, doi: 10.3390/w15030534.
- Shalaby, S. M., Hammad, F. A., and Zayed, M. E., 2023. Current progress in integrated solar desalination systems: Prospects from coupling configurations to energy conversion and desalination processes », *Process Safety and Environmental Protection*, vol. 178, p. 494-510, oct. 2023, doi: 10.1016/j.psep.2023.08.058.
- Shalaby, S. M., Zayed, M. E., Hammad, F. A., Menesy, A. S., and Abd Elbar, A. R., 2024. Recent advances in membrane distillation hybrids for energy-efficient process configurations: Technology categorization, operational parameters identification, and energy recovery strategies », *Process Safety and Environmental Protection*, vol. 190, Pp. 817-838, oct. 2024, doi: 10.1016/j.psep.2024.07.098.
- Singh, V., 2024. Water Resources , in *Textbook of Environment and Ecology*, V. Singh, Éd., Singapore: Springer Nature, 2024, Pp. 107-122. doi: 10.1007/978-981-99-8846-4_7.
- Sirota, R., Winters, G., Levy, O., Marques, J., Paytan, A., Silverman, J., and Bar-Zeev, E., 2024. Impacts of Desalination Brine Discharge on Benthic Ecosystems », *Environmental Science and Technology*, vol. 58, no 13, Pp. 5631-5645, 2024.
- Sola, I., Carratalá, A., Pereira-Rojas, J., Díaz, M. J., Rodríguez-Rojas, F., Sánchez-Lizaso, J. L., and Sáez, C. A., 2024. Assessment of brine discharges dispersion for sustainable management of SWRO plants on the South American Pacific coast », *Marine Pollution Bulletin*, vol. 207, Pp. 116905, oct. 2024, doi: 10.1016/j.marpolbul.2024.116905.
- Soliman, M. N., Guen, F. Z., Ahmed, S. A., Saleem, H., Khalil, M. J., and Zaidi, S. J., 2021. Energy consumption and environmental impact assessment of desalination plants and brine disposal strategies », *Process Safety and Environmental Protection*, vol. 147, p. 589-608, mars 2021, doi: 10.1016/j.psep.2020.12.038.
- Sun, Q., Gao, M., Wen, Z., Hou, G., Dang, X., Liu, S., and Zhao, G., 2023. Hydrochemical evolution processes of multiple-water quality interfaces (fresh/saline water, saline water/brine) on muddy coast under pumping conditions, *Science of The Total Environment*, vol. 857, p. 159297, janv. 2023, doi: 10.1016/j.scitotenv.2022.159297.
- Tareemi, A. A., and Sharshir, S. W., 2023. A state-of-art overview of multi-stage flash desalination and water treatment: Principles, challenges, and heat recovery in hybrid systems », *Solar Energy*, vol. 266, p. 112157, déc. 2023, doi: 10.1016/j.solener.2023.112157.
- Tu, W. H., Zhao, Y., Chan, W. P., and Lisak, G., 2024. Reclaimed seawater discharge – Desalination brine treatment and resource recovery system, *Water Research*, vol. 251, Pp. 121096, mars 2024, doi: 10.1016/j.watres.2023.121096.
- Vinothkumar, K., Shwetharani, R., and Balakrishna, R. G., 2023. Chapter 6 - Membrane-based separation technologies for zero liquid discharge », in *Concept of Zero Liquid Discharge*, C. M. Hussain et V. S. Kodialbail, Éd., Elsevier, 2023, p. 109-128. doi: 10.1016/B978-0-323-91745-2.00009-7.
- Wang, H., Yang, J., Zhang, H., Zhao, J., Liu, H., Wang, J., and Liang, H., 2024. Membrane-based technology in water and resources recovery from the perspective of water social circulation: A review », *Science of The Total Environment*, vol. 908, Pp. 168277, janv. 2024, doi: 10.1016/j.scitotenv.2023.168277.
- Wang, J., and Azam, W., 2024. Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries », *Geoscience Frontiers*, vol. 15, no 2, p. 101757, 2024.
- Xue, N., Lu, J., Gu, D., Lou, Y., Yuan, Y., Li, G., and Zhang, N., 2023. Carbon footprint analysis and carbon neutrality potential of desalination by electrodialysis for different applications », *Water Research*, vol. 232, p. 119716, avr. 2023, doi: 10.1016/j.watres.2023.119716.
- Yazdani, H., Baneshi, M., and Yaghoubi, M., 2023. Techno-economic and environmental design of hybrid energy systems using multi-objective optimization and multi-criteria decision making methods », *Energy Conversion and Management*, vol. 282, p. 116873, avr. 2023, doi: 10.1016/j.enconman.2023.116873.

