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Assessing the Effectiveness of Solar Photovoltaic Powered Reverse Osmosis Desalination Systems across Different Water Resources in Saudi Arabia

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Abstract

This study investigates the performance of a solar photovoltaic (PV)-powered reverse osmosis (RO) desalination system applied to diverse water sources in the Al-Baha region, Saudi Arabia, including seawater, groundwater, rainwater, municipal water, and brackish water. Key water quality parameters including Total Dissolved Solids (TDS), pH, Electrical Conductivity (EC), salinity, and Specific Gravity (SG) were measured before and after desalination to assess system effectiveness. Results showed significant reductions in TDS, EC, and salinity levels across all water types, with seawater and brackish water achieving salt rejection rates of 98.32% and 99.16%, respectively. Post-desalination TDS for seawater decreased from 25,000 mg/L to 420 mg/L and for brackish water from 11,900 mg/L to 100 mg/L, achieving potable standards. pH values remained stable within potable standards, while EC values for seawater and brackish water dropped from 50,000 µS/cm to 484 µS/cm and from 12,000 µS/cm to 95 µS/cm, respectively. Water recovery rates varied from 70% to 95.33%, with the highest recovery observed in rainwater and groundwater samples. The overall desalination efficiency was highest for seawater and brackish water, at 82.96% and 84.5%, respectively, demonstrating the PV-RO system's capability to provide high-quality, potable water from a variety of sources. This study underscores the potential of solar-powered RO technology as a sustainable solution for desalination in regions with diverse water sources and limited access to electricity.

Keywords

Solar Photovoltaic (PV)-Powered Reverse Osmosis, Water Sources

1. Introduction

Water scarcity has emerged as one of the most pressing global challenges of the 21st century. According to the United Nations, nearly two-thirds of the world's population is expected to experience water stress by 2025 [1]. Desalination, which involves the removal of salts and impurities from seawater and brackish water, offers a sustainable solution to this growing problem. It is particularly vital for regions, such as the Middle East, North Africa, and parts of Asia, where freshwater resources are insufficient to meet the needs of rapidly growing populations and expanding industrial activities [2]. Desalination plays a critical role in ensuring water security in regions where conventional water sources are inadequate. Countries like Saudi Arabia, and Australia have adopted desalination as a key component of their water supply strategies [3]. In Saudi Arabia, desalinated water contributes over 50% of the country's drinking water supply [4]. This is an example to demonstrate the significance of desalination in providing a stable and reliable source of freshwater, particularly in arid and semi-arid regions. Moreover, desalination helps mitigate the impacts of climate change and prolonged droughts on water availability. In Australia, for example, desalination plants were integrated into the national water infrastructure to combat the severe droughts of the early 21st century, ensuring a continuous supply of water even in times of low rainfall [5]. This ability to produce freshwater independently of climatic conditions makes desalination a crucial element of water resource management in the face of increasing environmental uncertainties [6]. Desalination not only addresses water scarcity but also promotes economic stability and growth. By providing a reliable source of water, it supports key sectors, such as agriculture, industry, and tourism. In countries like the United Arab Emirates (UAE), desalination has enabled the expansion of agricultural production in desert environments, reducing the dependency on food imports [2]. In addition, industries that require large quantities of water, such as petrochemical plants and manufacturing facilities, rely heavily on desalinated water to ensure uninterrupted operations [7]. While the cost of desalination remains higher compared to traditional water sources, advances in technology have significantly reduced operational costs. Innovations in membrane technology, particularly in reverse osmosis (RO) systems, have improved energy efficiency and lowered the cost of water production [8]. Solar-powered RO systems are generally more energy-efficient and cost-effective than traditional thermal desalination methods. Advancements in membrane technology and the decreasing cost of solar energy have reduced operational expenses, making solar-powered RO a competitive option [2]. For instance, modern RO plants can produce potable water at approximately \$0.30 per cubic meter, significantly lower than the over \$3 per cubic meter cost of older thermal plants [6]. RO membranes are susceptible to fouling from organic matter, scaling from dissolved salts, and biofouling by microorganisms. These issues can decrease system efficiency and increase maintenance costs. Mitigation strategies include regular chemical cleaning, pre-treatment of feed water, and the use of anti-scalant additives [7]. Moreover, the use of renewable energy sources such as solar and wind to power desalination plants is becoming increasingly feasible, further reducing the environmental and economic footprint of desalination [9]. Despite its benefits, desalination poses environmental challenges, particularly in terms of energy consumption and brine disposal. Desalination plants, especially those using RO technology, require significant amounts of energy, which can contribute to greenhouse gas emissions if powered by fossil fuels [10]. Solar photovoltaic (PV)-powered reverse osmosis (RO) desalination systems are increasingly being adopted as sustainable solutions for water scarcity, particularly in regions like Saudi Arabia with abundant solar resources. These systems significantly reduce the carbon footprint compared to fossil fuel-powered desalination, making them environmentally advantageous [11]. The integration of PV with RO has proven effective in desalinating both seawater and brackish groundwater, especially in off-grid and remote areas [12]. Continuous advancements in solar technology and membrane materials are improving energy efficiency and reducing costs [8]. Moreover, hybrid systems that combine solar energy with wind or other renewable sources are showing promise in ensuring consistent performance despite variable environmental conditions [13]. This approach is key to addressing Saudi Arabia's water security challenges, offering a sustainable alternative for water production across the Kingdom's diverse water resources [14]. The current study was conducted in the Al-Baha region, located in the southwestern part of Saudi Arabia. A fully integrated reverse osmosis desalination system was assembled to compare the effectiveness of desalinating various water sources across the Kingdom. High-precision instruments were employed to ensure accurate measurements, allowing for a reliable evaluation of the system's performance under different water quality conditions. This comprehensive approach provides valuable insights into the suitability of reverse osmosis technology for diverse water sources in the region.

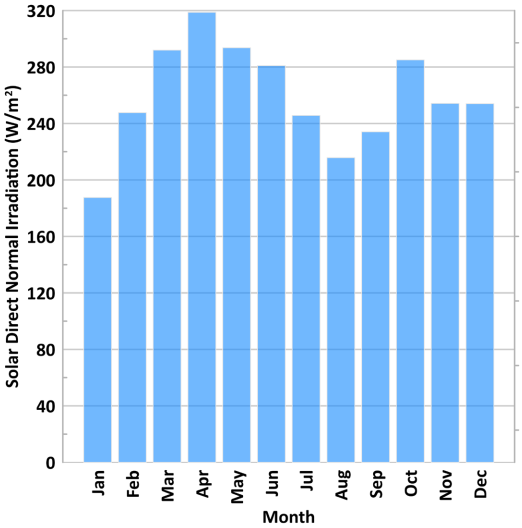

Figure 1. The changes in direct solar radiation throughout the year in Al-Baha region [15].

2. An Overview of Solar Direct Radiation in the Study Area

The current study was conducted in the Al-Baha region, located in the southwestern part of Saudi Arabia. The Al-Baha region is located in the southwest of Saudi Arabia, at a longitude of 41˚42'E and a latitude of 19˚20'N. It is considered one of the top tourist destinations in the southern part of the Kingdom. The System Advisor Model (SAM) software [15] was used to analyze the variation in solar direct radiation in this area. **Figure 1** illustrates the changes in direct solar radiation throughout the year in the study area, as generated by the SAM software. **Figure 1** demonstrates the suitability of the Al-Baha region for solar energy projects due to the high intensity of direct solar radiation throughout all seasons of the year.

3. Implementation of the Integrated Solar-Driven Desalination System

The desalination unit designed for this research is compact, fully portable, and ideal for deployment in remote areas. It is primarily powered by a solar panel, as illustrated in **Figure 2**. **Figure 3** provides the schematic diagram of the current circuit layout. The desalination process begins with the incoming water storage tank, where raw water is held prior to purification. The first pump, shown in **Figure 4(a)**, is a brushless DC pump with the following specifications: a maximum head of 300 cm, a maximum flow rate of 300 liters per hour, an operating voltage of 5 V DC, and a maximum operating temperature of 60˚C. This pump initially pressurizes the water, directing it through multiple filtration stages: a 5-micron polypropylene (PP) filter for removing large particles and sediment, a coconut shell-activated carbon filter for chlorine, chemicals, and odor removal, and a carbon block filter for further purification. Subsequently, a second pump, shown in **Figure 4(b)**, is a diaphragm pump with specifications including a maximum flow rate of 1.2 liters per minute, a pressure rating of 125 psi, and a 24V DC.

Figure 2. Current work portable desalination unit.

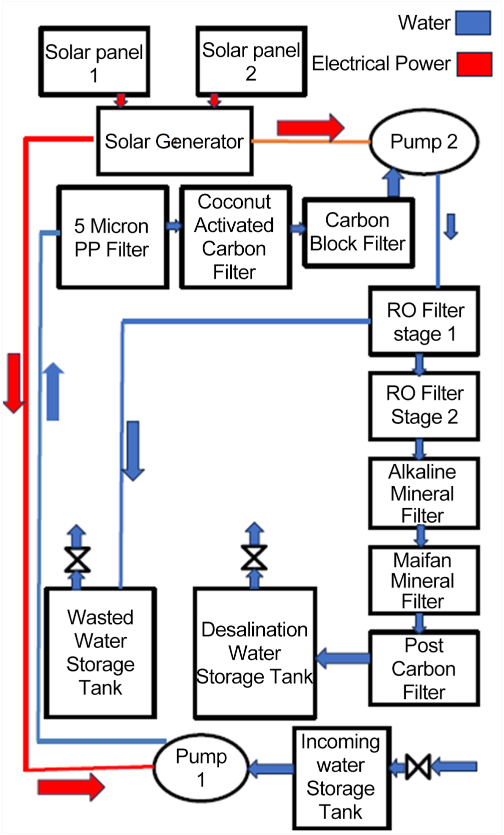

Figure 3. Schematic diagram for Current work portable desalination unit.

(a) Pump (1) (b) Pump (2)

Figure 4. Pumps use in the experimental circuit.

The second pump boosts water pressure to ensure effective flow through the reverse osmosis (RO) filters in stages 1 and 2, where dissolved salts, heavy metals, and other fine contaminants are removed. After this, the water passes through several post-filtration enhancements: a Maifan mineral filter, which adds essential minerals; an alkaline mineral filter, which balances pH for improved taste; and a post-carbon filter, which removes any residual odors or tastes. The purified water is then stored in a desalinated water storage tank for later use, while the wastewater storage tank collects brine, or rejected water, produced during the RO process.

The entire system operates sustainably, powered by two solar panels connected to a solar charge controller. Figure 5(a) and Figure 5(b) show the solar panel and its charge controller, respectively. Each solar panel has the following specifications: dimensions of 420 × 280 × 2.5 mm, monocrystalline 40 W, 18 V flexible photovoltaic module. The solar charge controller specifications include a rated voltage of 12 V/24 V, a rated current of 40 A, a maximum panel input voltage of 50 V, and maximum input power of 480 W (12 V) or 960 W (24 V). A solar generator supplies energy to the pumps and other electrical components, as shown in Figure 6(a) and Figure 6(b) for the front and back views, respectively. The generator provides both DC (12 V) and AC (110/220 V) outputs. This setup enables efficient desalination, making the system well-suited for environmentally friendly, off-grid operations.

(a) Solar panel (b) Solar charge controller

Figure 5. Solar panels with solar charge controller.

(a) Front view (b) Back view

Figure 6. Solar generator.

4. Methodology and Data Collection

4.1. General View

This study employed an integrated approach of design, implementation, and data analysis to develop and assess a portable, solar-powered desalination unit optimized for off-grid use across various water sources. The methodology involved designing and implementing a reverse osmosis (RO) desalination system powered by photovoltaic (PV) solar energy, ensuring sustainable and efficient water purification in Al-Baha region, Saudi Arabia. The desalination system design began with component selection, including the solar panels, charge controllers, and pumps, as well as pre-filtration and RO filtration units. Key design parameters focused on energy efficiency, durability, and the adaptability of the system to variable environmental conditions. The solar power generation system was designed to match the energy demands of the RO desalination unit and pumps, accounting for solar radiation levels, water demand rates, and desalination capacity requirements. For data collection and analysis, the System Advisor Model (SAM) software was employed to evaluate solar radiation data specific to the Al-Baha region. Using this data, SAM provided insights into the expected performance of the PV system under varying sunlight conditions, allowing for adjustments in system sizing to maximize power availability. Field tests on the installed system at Al-Baha University provided empirical data on water quality from different sources. The collected data was analyzed to evaluate the desalination efficiency. Regarding water quality, the best quality of desalinated water was determined based on the following parameters:

- Total Dissolved Solids (TDS): Ideal drinking water should have TDS levels less than 500 mg/L [16].
- pH: The recommended pH range for drinking water is between 6.5 and 8.5, with an optimal pH of 7 [17].
- Electrical Conductivity (EC): EC values for potable water should be less than 1000 µS/cm [18].
- Salt: The concentration of salts in desalinated water should be low, ideally under 500 mg/L to ensure safe consumption and optimal taste [19].
- Specific Gravity (SG): The specific gravity of fresh water should ideally be close to 1.0, as it indicates the absence of significant dissolved solids or impurities [20].

4.2. Measurement Instrument

In this study, we employ the PH-W3988 WiFi Water Quality Monitor, as illustrated in **Figure 7**, to perform comprehensive water quality assessments by leveraging its multi-parameter capabilities for in-depth analysis. The PH-W3988 is an advanced, multi-parameter water analysis device that enables real-time monitoring of six essential water quality indicators: pH, electrical conductivity (EC), total dissolved solids (TDS), salinity (SALT), specific gravity (SG), and temperature. This 6-in-1 monitor is equipped with WiFi connectivity, allowing seamless data transfer to a smartphone application for remote monitoring. This functionality makes it particularly well-suited for professional and industrial contexts where ensuring consistent water quality is critical.

Figure 7. PH-W3988 WiFi water quality monitor.

4.3. Data Collection

In the present study, data collection involved obtaining water samples from various sources in the Al-Baha region, including seawater, groundwater, rainwater, local network water, and brackish water. Each sample was carefully collected following standard water sampling procedures to ensure accuracy and reliability in measuring quality parameters. Samples were analyzed both before and after desalination to assess the performance of the PV-RO desalination system. Parameters measured included total dissolved solids (TDS), pH, electrical conductivity (EC), salinity (SALT), specific gravity (SG), and temperature. These measurements were conducted using the PH-W3988 WiFi Water Quality Monitor, a multi-parameter instrument chosen for its precision and ability to provide real-time data via smartphone connectivity. This device enabled consistent monitoring across diverse water sources, ensuring a comprehensive evaluation of desalination effectiveness.

4.4. Desalination Efficiency Calculation

Desalination efficiency typically refers to how effectively a desalination system removes salts and other dissolved solids from water. It can be evaluated in several ways. First with the most common metrics focusing on salt rejection rate and water recovery rate. Salt rejection rate measures how effectively the system removes dissolved salts (usually in terms of TDS) from the input water [20].

$$salt\,rejection\,rate(\%) = \left(1 - \frac{TDS_{OUT}}{TDS_{IN}}\right) \times 100 \tag{1}$$

where:

TDS_{in}: Total Dissolved Solids in the feed (input) water before desalination (measured in mg/L).

TDS_{out}: Total Dissolved Solids in the feed (input) water after desalination (measured in mg/L).

A higher salt rejection rate indicates a more efficient desalination process in terms of removing dissolved solids. Second with water recovery rate refers to the percentage of input water that is converted into purified water (permeate) in the desalination process. This rate indicates the amount of purified water generated from a given volume of raw (feed) water. A high-water recovery rate means that the system produces more clean water with less waste. This rate is calculated as [21] [22]:

$$\text{Water Recovery Rate}(\%) = \left(\frac{\text{Volume of Permeate}}{\text{Volume of Feed Water}}\right) \times 100 \tag{2}$$

While the two metrics above are usually evaluated separately, they can also be combined to give an overall idea of system efficiency. A system with high salt rejection and high-water recovery is generally considered more efficient, which is calculated from the following equation [23]:

$$\text{Overall Desalination Efficiency}(\%) = (\text{Salt Rejection Rate X Water Recovery Rate})^{\frac{1}{2}} \tag{3}$$

This combined efficiency gives a balanced view of both salt removal and water productivity.

5. Results and Discussions

5.1. Data Collected Analysis

The solar photovoltaic (PV)-powered reverse osmosis (RO) desalination system's performance was evaluated using samples from various Al-Baha water sources, including seawater, groundwater, rainwater, municipal water, and brackish water. Table 1 shows pre- and post-desalination results, highlighting effective reductions in TDS, with the most notable drops in seawater (from 25,000 mg/L to 420 mg/L, 98.32% reduction) and brackish water (from 11,900 mg/L to 100 mg/L, 99.16% reduction). Groundwater and rainwater also experienced TDS reductions from lower initial values. Post-desalination pH levels stayed within potable standards (6.5 - 8.5), with minor adjustments observed. Significant EC reductions occurred in all samples, especially seawater and brackish water (from 50,000 and 12,000 μS/cm to 484 and 95 μS/cm, respectively), confirming reduced ion concentrations. Salinity decreased notably, from 30,000 mg/L in seawater to 0.282 mg/L, and from 14,000 mg/L in brackish water to 114 mg/L, indicating high salt rejection efficiency. SG values were minimal post-desalination, approximating 1.0 (pure water SG). The system's water recovery rates varied from 70% to 95%, with higher recovery in low-salinity sources like rainwater and groundwater, while seawater and brackish water required more filtration effort.

Table 1. Overview of various water samples.

Sample No.	1		2		3		4		5	
Water source	Seawater		Groundwater		Rainwater		Network water		Brackish water	
Desalination	Before	After	Before	After	Before	After	Before	After	Before	After
TDS, mg/L	25,000	420	468	378	50	10	742	190	11,900	100
pH	8.5	8	8.06	7.92	7	7.5	8.07	7.86	7.4	8
EC, µS/cm	50,000	484	930	750	50	20	980	370	12,000	95
SALT, mg/L	30,000	0.282	543	241	241	130	863	219	14,000	114
SG	1.03	1	1.005	0.997	1.001	0.997	1	0.997	1.011	0.997
Volume, L	15	10.5	15	14.3	15	12.3	15	12.6	15	10.8
Temperature	25.6˚C (During measurements)									

Table 2 summarizes the desalination efficiency for different water sources, detailing salt rejection, water recovery, and overall efficiency. The salt rejection rate varied significantly, from 19.23% in sample 2 to 99.16% in sample 5, demonstrating strong salt removal capability in most samples, especially Samples 1 (98.32%) and 5 (99.16%). A low salt rejection rate, such as the 19.23% observed in sample 2, may result from membrane fouling, improper membrane selection, suboptimal operating conditions or initial salt concentrations might affect performance [23]. Water recovery rates were generally high, ranging from 70% (sample 1) to 95.33% (sample 2), with most samples achieving over 80%. Overall efficiency ranged from 42.81% (sample 2) to 84.5% (sample 5), with samples 1 and 5 showing the highest efficiencies. These results indicate that while the system is effective overall, performance varies depending on water sample characteristics, suggesting possible benefits from pre-treatment or adjustments for samples with lower rejection rates like sample 2.

Table 2. Desalination efficiency values obtained in this study across various water sources.

Sample No.	Salt rejection rate (%)	Water Recovery Rate (%)	Overall efficiency (%)
1	98.32	70	82.96
2	19.23	95.33	42.81
3	80	82	81
4	74.39	84	79.05
5	99.16	72	84.5

5.2. Parametric Study of Water Sources Quality

The parametric study in this research, summarized in Table 1 and Table 2, examined desalination performance across various water sources through a series of comparative figures. Figure 8 illustrates the reduction in Total Dissolved Solids (TDS) before and after desalination, highlighting significant improvements, especially for seawater and brackish water. Specific Gravity (SG) values before and after treatment are shown in **Figure 9**, where post-desalination values approach that of pure water. **Figure 10** displays Electrical Conductivity (EC) changes, with substantial reductions across samples, further evidencing ion removal. The pH adjustments shown in **Figure 11** indicate that desalination has minimal impact on pH, maintaining it within potable standards. Salinity (SALT) levels, captured in **Figure 12**, show effective salt removal, particularly in higher-salinity sources. **Figure 13** demonstrates water volume recovery, which remained high, reflecting efficient water use.

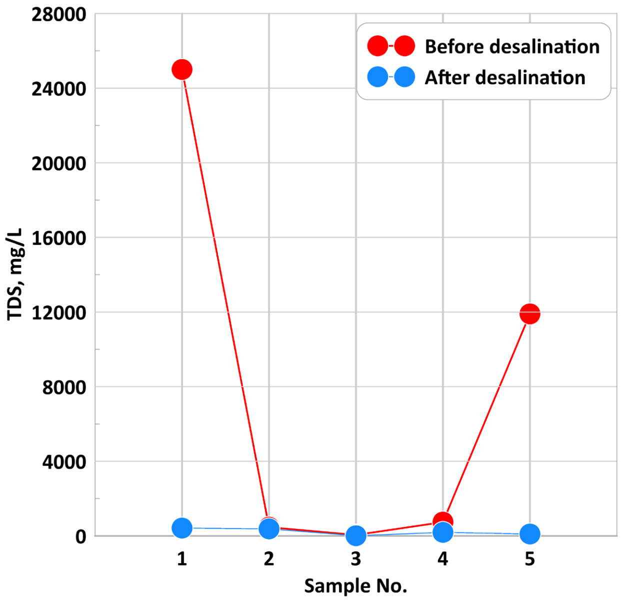

Figure 8. TDS before and after desalination for all samples.

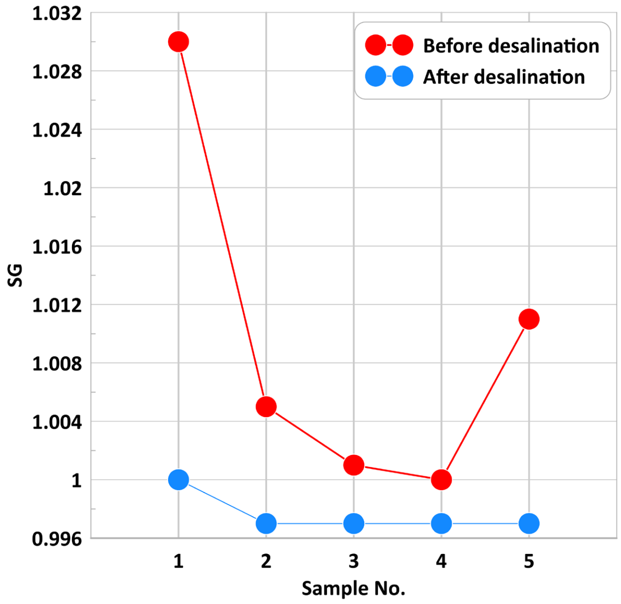

Figure 9. SG before and after desalination for all samples.

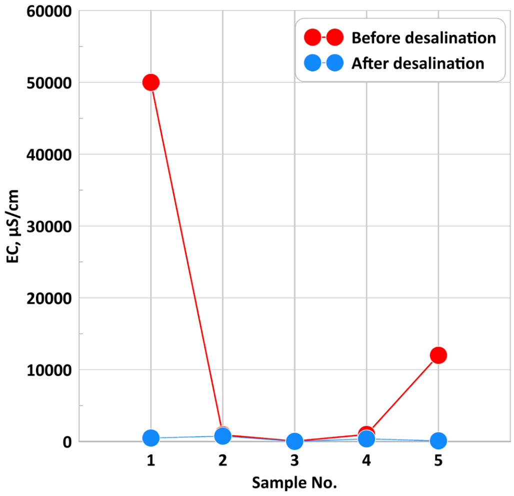

Figure 10. EC before and after desalination for all samples.

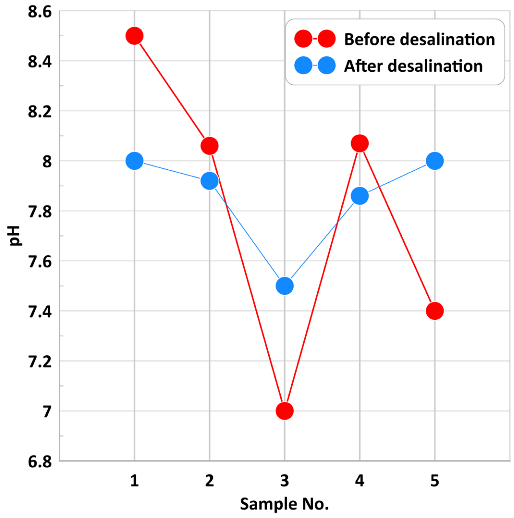

Figure 11. pH before and after desalination for all samples.

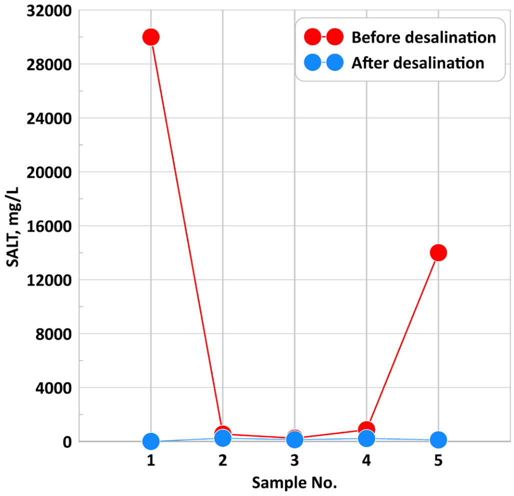

Figure 12. SALT before and after desalination for all samples.

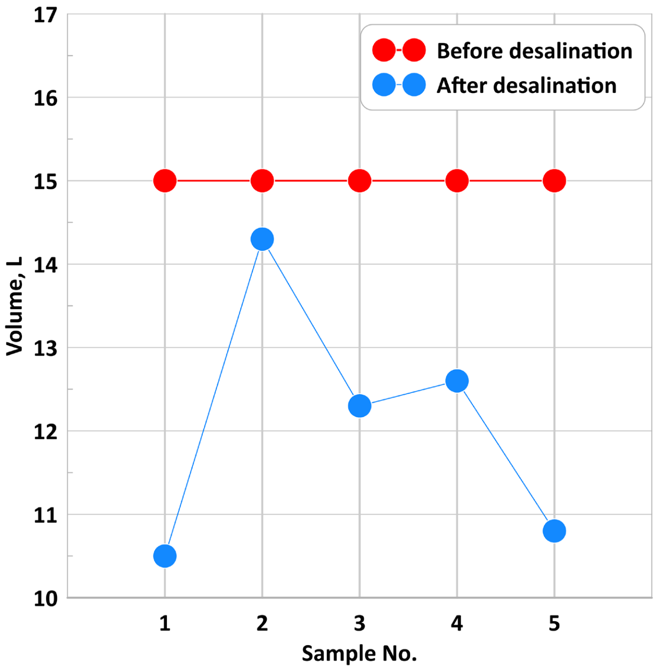

Figure 13. Water volume before and after desalination for all samples.

Rejection rates for all samples are illustrated in Figure 14, with strong performance on higher-salt samples. Water recovery rates, shown in Figure 15, were highest in samples with lower initial TDS. Finally, Figure 16 combines salt rejection and water recovery to show overall desalination efficiency, with optimal results achieved for seawater and brackish water samples. This study thus reveals the system's adaptability and effectiveness across diverse water sources.

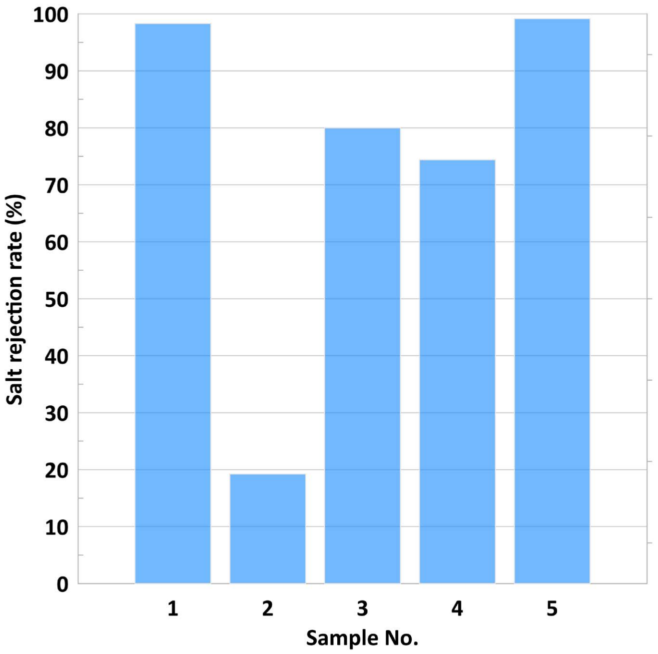

Figure 14. Rejection rates for all samples.

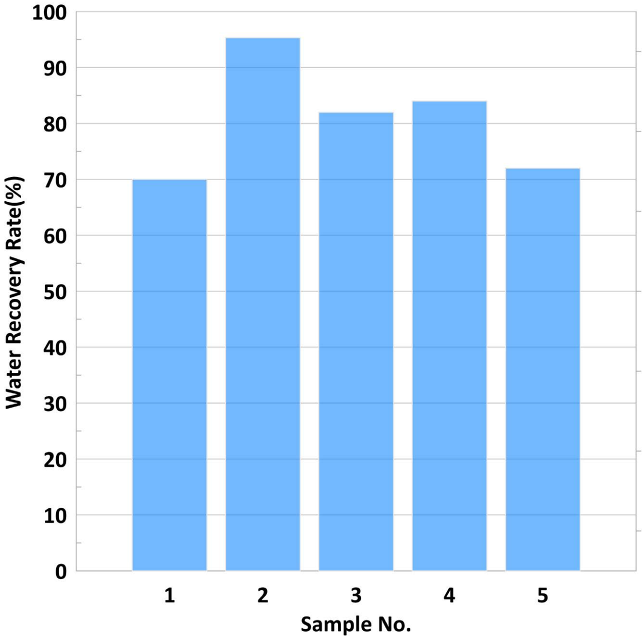

Figure 15. Water recovery rates for all samples.

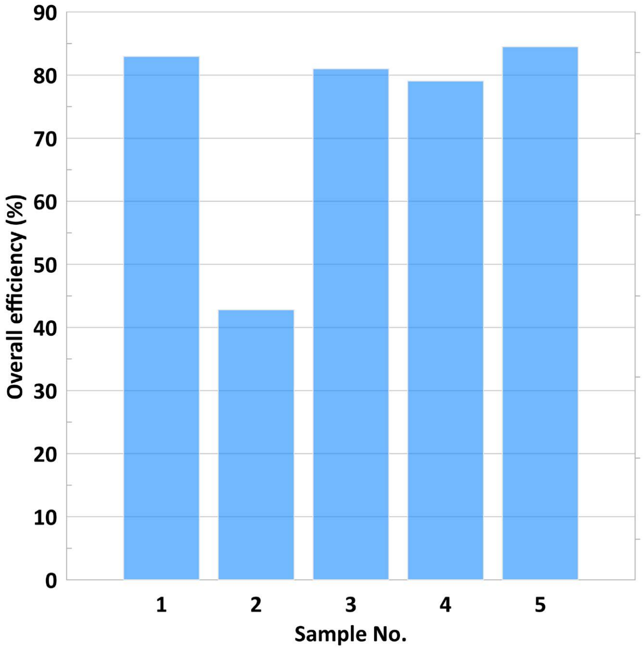

Figure 16. Overall desalination efficiency for all samples.

6. Conclusions

Scaling solar-powered RO systems requires careful consideration of energy supply, infrastructure, and environmental impact. Large-scale implementations demand substantial solar panel installations and energy storage solutions to ensure continuous operation. Additionally, the disposal of concentrated brine byproducts must be managed to minimize environmental harm. Despite these challenges, successful large-scale projects, such as the Hassyan desalination plant in Dubai, demonstrate the viability of scaling up, with capacities reaching up to 818,000 cubic meters per day [3]. The current study assessed a solar PV-powered reverse osmosis (RO) desalination system for water sources in Al-Baha, Saudi Arabia, focusing on seawater, brackish water, groundwater, rainwater, and municipal water. Key findings indicate:

1) High salt rejection rates: 98.32% for seawater and 99.16% for brackish water, highlighting strong salt removal capabilities.

2) Effective water recovery, with rates up to 95.33% for rainwater and groundwater, showing efficient conversion of input water into potable water.

3) Water quality improvements by significant reductions in TDS, EC, and salinity across samples, achieving potable standards. In addition, stable pH adjustments, maintaining levels within potable water standards (6.5 - 8.5).

4) Performance variability since lower salt rejection efficiency observed in low-salinity sources (e.g., certain groundwater), suggesting possible benefits from system optimization for specific water chemistries.

This research confirms the PV-RO system as a viable, sustainable desalination solution for diverse water sources, particularly valuable in off-grid and energy-limited regions.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Pltonykova, H., *et al.* (2020) The United Nations World Water Development Report 2020: Water and Climate Change. UNESCO.

[2] Ghaffour, N., Missimer, T.M. and Amy, G.L. (2013) Technical Review and Evaluation of the Economics of Water Desalination: Current and Future Challenges for Better Water Supply Sustainability. *Desalination*, **309**, 197-207. https://doi.org/10.1016/j.desal.2012.10.015

[3] Elimelech, M. and Phillip, W.A. (2011) The Future of Seawater Desalination: Energy, Technology, and the Environment. *Science*, **333**, 712-717. https://doi.org/10.1126/science.1200488

[4] Einav, R., Harussi, K. and Perry, D. (2003) The Footprint of the Desalination Processes on the Environment. *Desalination*, **152**, 141-154. https://doi.org/10.1016/s0011-9164(02)01057-3

[5] Roberts, D.A., Johnston, E.L. and Knott, N.A. (2010) Impacts of Desalination Plant

Discharges on the Marine Environment: A Critical Review of Published Studies. *Water Research*, **44**, 5117-5128. https://doi.org/10.1016/j.watres.2010.04.036

[6] Shannon, M.A., Bohn, P.W., Elimelech, M., Georgiadis, J.G., Mariñas, B.J. and Mayes, A.M. (2008) Science and Technology for Water Purification in the Coming Decades. *Nature*, **452**, 301-310. https://doi.org/10.1038/nature06599

[7] Greenlee, L.F., Lawler, D.F., Freeman, B.D., Marrot, B. and Moulin, P. (2009) Reverse Osmosis Desalination: Water Sources, Technology, and Today's Challenges. *Water Research*, **43**, 2317-2348. https://doi.org/10.1016/j.watres.2009.03.010

[8] Shenvi, S.S., Isloor, A.M. and Ismail, A.F. (2015) A Review on RO Membrane Technology: Developments and Challenges. *Desalination*, **368**, 10-26. https://doi.org/10.1016/j.desal.2014.12.042

[9] Caldera, U., Bogdanov, D., Afanasyeva, S. and Breyer, C. (2017) Role of Seawater Desalination in the Management of an Integrated Water and 100% Renewable Energy Based Power Sector in Saudi Arabia. *Water*, **10**, Article 3. https://doi.org/10.3390/w10010003

[10] Jones, E., Qadir, M., van Vliet, M.T.H., Smakhtin, V. and Kang, S. (2019) The State of Desalination and Brine Production: A Global Outlook. *Science of the Total Environment*, **657**, 1343-1356. https://doi.org/10.1016/j.scitotenv.2018.12.076

[11] Al-Karaghouli, A. and Kazmerski, L.L. (2013) Energy Consumption and Water Production Cost of Conventional and Renewable-Energy-Powered Desalination Processes. *Renewable and Sustainable Energy Reviews*, **24**, 343-356. https://doi.org/10.1016/j.rser.2012.12.064

[12] Ghaithan, A.M., Mohammed, A., Al-Hanbali, A., Attia, A.M. and Saleh, H. (2022) Multi-Objective Optimization of a Photovoltaic-Wind-Grid Connected System to Power Reverse Osmosis Desalination Plant. *Energy*, **251**, Article ID: 123888. https://doi.org/10.1016/j.energy.2022.123888

[13] Ricart, S., Villar-Navascués, R.A., Hernández-Hernández, M., Rico-Amorós, A.M., Olcina-Cantos, J. and Moltó-Mantero, E. (2021) Extending Natural Limits to Address Water Scarcity? The Role of Non-Conventional Water Fluxes in Climate Change Adaptation Capacity: A Review. *Sustainability*, **13**, Article 2473. https://doi.org/10.3390/su13052473

[14] Eltamaly, A.M., Ali, E., Bumazza, M., Mulyono, S. and Yasin, M. (2021) Optimal Design of Hybrid Renewable Energy System for a Reverse Osmosis Desalination System in Arar, Saudi Arabia. *Arabian Journal for Science and Engineering*, **46**, 9879-9897. https://doi.org/10.1007/s13369-021-05645-0

[15] Laboratory, N.R.E. (2024) System Advisor Model (SAM). https://sam.nrel.gov/

[16] World Health Organization (2013) World Health Report 2013: Research for Universal Health Coverage.

[17] Grossarth, S.K. and Hecht, A.D. (2007) Sustainability at the U.S. Environmental Protection Agency: 1970-2020. *Ecological Engineering*, **30**, 1-8. https://doi.org/10.1016/j.ecoleng.2006.09.011

[18] Recommendations from World Health Organization (2011) Guidelines for Drinking-Water Quality. Vol. 38, 104-108.

[19] Post, G.B. (2020) Recent US State and Federal Drinking Water Guidelines for Per- and Polyfluoroalkyl Substances. *Environmental Toxicology and Chemistry*, **40**, 550-563. https://doi.org/10.1002/etc.4863

[20] Omer, N.H. (2019) Water Quality Parameters. *Water Quality—Science, Assessments and Policy*, **18**, 1-34.

[21] Baker, R.W. (2023) Membrane Technology and Applications. Wiley. https://doi.org/10.1002/9781119686026

[22] Spellman, F.R. (2008) Handbook of Water and Wastewater Treatment Plant Operations. CRC Press.

[23] Voutchkov, N. (2014) Desalination Engineering: Operation and Maintenance. McGraw Hill Professional.