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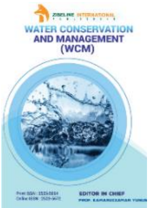

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RESEARCH ARTICLE

DEVELOPMENT OF A SUSTAINABLE TECHNOLOGY FOR THE DISPOSAL OF CHEMICAL RESIDUES INTEGRATED ON MOBILE DESALINATION UNITS OF MINERALIZED WATER IN REMOTE PASTORAL AREAS

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ABSTRACT

The rapid development of mineral water desalination technologies, particularly for pasture-based livestock farming in remote regions, has resulted in the generation of substantial volumes of highly concentrated brines and regenerating chemical solutions. The uncontrolled discharge of these waste streams poses serious environmental threats, including soil salinization and groundwater contamination. This study aims to develop and experimentally validate a sustainable technology for the disposal and reuse of brines and wash solutions produced during the desalination of mineralized water using a mobile reverse osmosis (RO) unit. To minimize environmental impacts, a comprehensive methodological framework combining analytical, experimental, functional, and statistical approaches was applied to identify weaknesses in existing desalination methods and to assess the performance of a vacuum evaporation system. The chemical composition of the treated mineral water was analyzed, and a bench-scale vacuum evaporator was designed and tested. The proposed process scheme for the mobile RO unit includes a vacuum evaporation module capable of achieving a vacuum of –0.7 bar and a heating temperature of up to 60 °C, enabling efficient brine concentration, regeneration of chemical solutions, complete liquid waste recycling, and recovery of dry residues, while returning distilled water to the desalination cycle. The developed technology can be applied for irrigation of remote pastures and to improve the environmental performance and cost efficiency of industrial water treatment systems.

KEYWORDS

Desalination, mineralized water, brine disposal, vacuum evaporation, reverse osmosis, wastewater recycling, sustainable water treatment.

1. INTRODUCTION

The rapid technological advancement of agriculture in recent decades has led to an increasing demand for sustainable and reliable water-supply systems, particularly in arid and semi-arid regions (Qiblawey and Banat, 2020; Mekonnen and Hoekstra, 2021). As water-quality requirements become more stringent, the modernization of existing water-supply infrastructure and the development of new treatment technologies have accelerated worldwide (Gude, 2022; Subramani and Jacangelo, 2021). However, significant challenges persist in the desalination of mineralized waters. Many existing systems exhibit methodological and operational inefficiencies that lead to the generation of large volumes of waste, including clarifier sludge, regeneration solutions, ion-exchange concentrates, and reverse osmosis (RO) brines. Improper disposal of these waste streams can cause severe environmental degradation, negatively affecting soils, groundwater, and surrounding ecosystems (Panagopoulos et al., 2019; Adewale et al., 2021; Banerjee et al., 2025). In Kazakhstan for example, approximately 118.2 million m^3 of water— around 1% of the nation's total water use—is allocated for pasture irrigation, with roughly equal reliance on surface and groundwater sources (Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan, 2023). Seasonal and remote pastures face logistical and water-quality constraints, especially in supplying potable water for herders and livestock. According to national sanitary regulations, mineralized water with total dissolved solids (TDS) up to 5 g/L may be used for watering small ruminants and camels, whereas water for human consumption must not exceed 1 g/L TDS. In many remote sites, delivered water is often of low quality and incurs high transportation costs due to distances exceeding 15–20 km from supply sources. Thus, mobile desalination units represent a practical alternative, particularly as temporary or emergency systems when centralized water-supply infrastructure fails (Chen et al., 2022; Zhao et al., 2021). The deployment of mobile RO units in pasture areas depends on the spatial distribution of wells, road conditions, and travel distances between stations. Nevertheless, mobile desalination remains capital- and energy-intensive, with brine-disposal emerging as a primary environmental challenge (Al-Marzooqi et al., 2024). Techno-economic assessments of desalination options for weakly to highly mineralized waters consistently identify RO as the most cost-effective and operationally reliable solution for remote water-supply systems (Karagiannis and Soldatos, 2023; Ghaffour et al., 2019). In such conditions, transporting potable water over long distances, often 40–50 km, can be several times more expensive than on-site desalination. A critical issue in this context is the management and valorization of concentrated brine. Brine is an unavoidable by-product of desalination processes, and its

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improper disposal can lead to salinization, toxicity, and disruption of aquatic ecosystems (Panagopoulos, 2019). Recent studies highlight the urgency of transitioning toward zero-liquid-discharge (ZLD) and circular-economy approaches that recover valuable salts and water from brines (Lee et al., 2023; Kumari et al., 2024; Rivero-Falcón et al., 2023). As emphasize the sustainability benefits of ZLD systems and the need for integrated brine management in inland desalination plants, while report the emerging potential for resource recovery from brine streams through evaporation, crystallization, and chemical regeneration (Panagopoulos, 2019; Lee et al., 2023; Panagopoulos et al., 2019). Kazakhstan possesses considerable but underutilized groundwater resources, estimated at 64.28 km^3/year, of which 15.56 km^3/year are deemed exploitable (Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan, 2023). However, approximately 46% of these resources are mineralized and require desalination, equivalent to around 7.1 km^3 annually. Given that RO systems dominate Kazakhstan's desalination infrastructure (>90%), typically generating concentrate streams of 20–25%, the volume of brine requiring environmentally safe management exceeds 1.4 km^3 per year (Shestakov and Mussina, 2022). Thus, sustainable brine disposal and regeneration technologies are crucial for the long-term development of water resources, not only in Kazakhstan but worldwide. This study aims to address these challenges by developing and experimentally validating an integrated technology for mineral-water desalination that includes vacuum-assisted brine evaporation and chemical-solution regeneration. The proposed system seeks to improve environmental performance, minimize waste generation, and enhance operational efficiency for mobile desalination units deployed in remote pasture-based water-supply applications.

2. MATERIALS AND METHODS

A comprehensive experimental study on mineralized water desalination was carried out to investigate both theoretical and practical aspects of brine and regeneration solution management. Laboratory modeling of the desalination process was performed using a combination of analytical, statistical, and functional research approaches. The analytical approach was applied to identify key challenges in mineral water desalination, particularly the disposal of concentrated brines generated during the process and the management of wash solutions produced during reverse osmosis (RO) membrane rinsing. The statistical approach was used to assess performance indicators, determine potential design and operational errors in the development of the mobile RO unit, and evaluate its applicability for use with open evaporation pads. The functional approach focused on evaluating the environmental and operational role of brine and regeneration solution disposal in mobile RO desalination systems. This included assessing the system's efficiency, advantages, limitations, and overall environmental impact under field-like conditions. Experimental testing of the mobile RO unit was conducted to evaluate key parameters of the evaporation process. The statistical analysis of experimental data included the ratio of solution volume to evaporated liquid under vacuum pressures up to -0.7 bar and solution heating temperatures reaching 60 °C. Chemical and physical analytical methods were applied to characterize the process efficiency and solution composition. The experimental setup consisted of a compact, modular assembly with all units installed within the vehicle body, enabling on-site operation and testing.

2.1 Experimental Setup

A mobile desalination unit equipped with a vacuum brine utilization module is proposed for the first time, representing a novel solution absent in existing industrial systems (Figure 1). An intelligent control unit was developed to enable automatic adjustment of process parameters in response to changes in brine salinity and temperature, thereby improving both the stability and energy efficiency of the desalination process. The system incorporates a comprehensive approach to energy optimization, allowing the use of electric heating as well as alternative heat sources, including solar collectors. A low-temperature vacuum evaporation scheme operating at reduced pressure (-0.2 bar) has been implemented, significantly extending the operational range under various climatic conditions. This approach is particularly advantageous in regions with limited solar radiation, where conventional solar evaporators perform inefficiently. The technological scheme of the mobile desalination unit (Figure 1) illustrates a compact system designed to treate mineralized water with salinity levels up to 5 g/L and a throughput of 1 m^3/h. The unit is intended for deployment in remote pasture areas of Kazakhstan (~180 million hectares).

Figure 1: Interior view of the mobile desalination system

The rear compartment of the trailer (Figure 1) houses feedwater and permeate tanks, equipped with feed pipes, drain connections, and control valves. The central compartment contains a factory-assembled reverse osmosis system with a high-pressure pump, pre-filters, and two ESPA-4040 membrane elements. A vacuum evaporation system, developed and patented in Kazakhstan, is integrated for the treatment of brine and regeneration solutions. LKS-250PW circulation pumps operate in the feedwater supply line and recirculation loop. Membranes are cleaned every 300–500 hours using 10% acidic or alkaline solutions (technical citric acid or sodium tripolyphosphate), depending on water mineralization. The primary objective of this experimental setup is to perform laboratory-scale studies on brine and regeneration solution utilization during mineralized water desalination using the mobile RO unit.

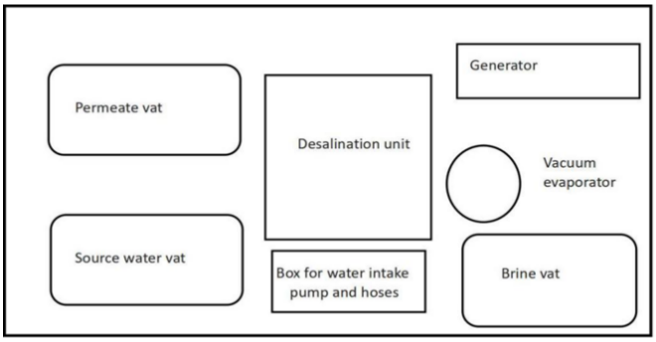
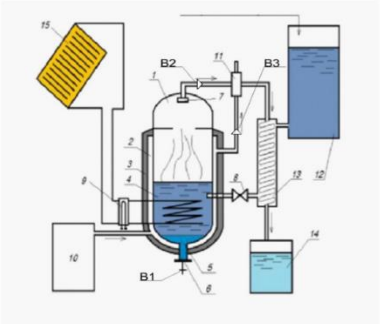


Figure 2: Arrangement of process equipment on a mobile unit

2.2 Vacuum Evaporator For Brine Disposal

In the process flow diagram of the mobile desalination unit (MDU) incorporating reverse osmosis modules, a vacuum evaporator is proposed for the treatment and disposal of concentrated brine (Figure 2). Heating of the feed brine can be provided through the recovery of waste exhaust heat from the power generator, as well as by electric heating elements, solar energy, or other auxiliary heat sources. Vacuum generation is achieved using an ejector (Venturi device). The proposed technological configuration is protected by Patent of the Republic of Kazakhstan No. 6827. To evaluate the operational stability and performance of the vacuum-evaporation module, laboratory experiments were conducted over a 100-hour testing period.



1.- vacuum evaporator 2 - exhaust gas jacket 3. - insulation 4. - original brine 5.- salt sediment 6. - hatch for unloading sediment 7.- drip collector 8.- initial brine dispenser	9. - Heating element. 10. - electric generator 11. - ejector (Venturi tube) 12. - storage tank for the initial brine 13.- capacitor 14. - distillate 15. -solar water heater.

Figure 3: Operating diagram of a vacuum evaporator

During the desalination process, or during the utilization of the regeneration solutions (technical citric acid or sodium tripolyphosphate), the resulting brine is transferred into the brine tank (1), which initiates the operation of the compressor (3). Subsequently, valves B3 and B2 are opened, generating a vacuum in the vacuum evaporator tank (2). Once valve B1 is opened, the evaporator tank (2) begins to fill to the designated level, which is continuously monitored using a water-level gauge (5). When the tank reaches the required capacity, valves B1, B2, and B3 are closed, and the heating element is activated to raise the temperature of the liquid to 50–60 °C. Temperature control is performed using an electronic temperature sensor connected to the condenser (6). After the brine reaches the target temperature, the evaporation process is initiated following the predefined sequence. Vacuum conditions are monitored using a pressure gauge (7), with measured vacuum levels occasionally reaching -0.6–0.7 bar. The air–vapor mixture produced during evaporation is directed into the condenser, where it is cooled and subsequently collected as distillate. The condenser consists of a horizontal plastic tube housed within a cylindrical plastic casing, through which air from the compressor flows in a countercurrent direction relative to the air–vapor stream before being discharged to the atmosphere. In this system, the compressor maintains the required pressure differentials, while the condenser ensures sufficient cooling of the vapor mixture to promote condensation. The vacuum evaporation unit is intended for the purification and concentration of solutions containing various chemical compounds, including salts, acids, alkalis, and organic substances. Under reduced pressure, evaporation occurs at lower temperatures, enabling concentration of the feed solution with reduced energy and reagent consumption. Monitoring of the operating conditions is carried out using a water-level gauge and a vacuum pressure gauge, while an electronic temperature sensor provides continuous control of solution temperature throughout the evaporation process. Vacuum generation is achieved using an ejector (Venturi device), which creates a low-pressure zone by ejecting the steam stream from the condenser in accordance with the principle of conservation of energy.

3. Results and Discussion

Short-term tests of the proposed schemes showed that the use of an ejector (Venturi tube) with flue gases from the electric generator does not allow achieving a vacuum greater than 1 bar. At the same time, increasing the brine temperature leads to a significant increase in electricity consumption (and consequently fuel consumption) for evaporating 1 L of brine. A vacuum pump should then be incorporated into the system, and the effect of brine salinity was considered, as it influences the productivity of the evaporation process. Thus, the proposed technological scheme allows for the utilization of brines obtained during the water desalination process, as well as for the regeneration of rinse solutions used to restore the selectivity of reverse osmosis membranes. Membrane regeneration is preferably carried out at a centralized facility connected to stationary energy networks. The evaporation rate of brine depends on multiple factors, including gas temperature, vacuum depth, brine salinity, and others, and determined during production trials of the mobile unit. The results of the conducted laboratory studies are presented in Table 1.

Table 1: Results of Laboratory Studies of the Vacuum Evaporator for Brine Utilization

Volume of feed brine, L	Brine heating temperature, °C	Evaporated brine volume, L/h	Distillate volume, L/h	Electricity consumption for heating, kWh/L	Note
100	40	4	3,2	0,2	The evaporator was operated 8 hours per day for 20 days with continuous replenishment of brine, which had a salinity of 7.5 g/L.
100	40	4	3,2	0,2	
100	40	4	3,2	0,2	
100	40	4	3,2	0,2	
100	40	4	3	0,21	
100	50	4,5	3,3	0,25	
100	50	4,3	3,6	0,25	
100	50	4,3	3,6	0,25	
100	50	4,3	3,6	0,25	
100	50	4,3	3,6	0,25	

Table 1 (cont): Results of Laboratory Studies of the Vacuum Evaporator for Brine Utilization

100	60	4,5	3,8	4,1	Vacuum level: -0.2 bar
100	60	4,5	3,8	4,0	
100	60	4,6	3,70	4,0	
100	60	4,5	3,75	4,0	
100	60	4,5	3,75	4,0	
100	70	4,1	3,1	4,5	
100	70	4,0	3,2	4,5	
100	70	4,1	3,2	4,5	
100	70	4,1	3,2	4,3	
100	70	4,1	3,1	4,3	
100	80	4,2	3,1	4,7	
100	80	4,0	3,3	4,7	
100	80	4,0	3,3	4,8	
100	80	4,2	3,3	4,7	
100	80	4,2	3,3	4,7	

Based on studies using the vacuum brine utilization method, it was found that the average productivity of the vacuum evaporator is approximately 4 L/h, whereas the productivity of open evaporation ponds at an average air temperature above 25 °C is about 0.9 L/h, as shown in the comparative analysis given in Table 2. Thus, the proposed vacuum evaporation technology for brine utilization demonstrates significantly higher productivity, approximately ten times greater than conventional brine disposal methods, and is capable of efficient operation under various climatic conditions, including periods of sub-zero ambient temperatures.

Based on production trials of the mobile desalination unit, an assessment was conducted according to reliability criteria, including an analysis of failures in individual components during testing. Reliability indicators were determined, including mean time to failure (MTTF), failure rate, downtime factor, maintainability coefficient, time required for repair, operational cost factor, and other parameters. It was established that during continuous operation of the unit for 300 hours, no failures were recorded that reduced its operational capability, corresponding to the operational reliability coefficient assumed in the design, K = 0.95.

Table 2: Comparative parameter analysis between the performance of the developed vaccum evaporator (-0.2 bar) and the evaporation pond

Parameter	Vacuum evaporator	Evaporation pond
Performance, L/h	4,0–4,5	0,8–0,9
Operating temperature, °C —	40–70	≥ 25
Energy consumption, kWh/L	0,2–0,25	—
Seasonal applicability	Year-round	Summer period only
Vacuum level	-0,2 bar	—
Brine utilization	Full	Partial
Reliability coefficient	0,95	—

Ultimately, preliminary bench tests of the vacuum evaporator circuit and its connection to the brine tank demonstrated the ability to create a vacuum of up to -0.7 bar. At this vacuum level and with the solution heated to 60°C, two processes occur: boiling and evaporation. Table 3 lists the evaporation process parameters, namely, solution volume, temperature, vacuum level, volume of evaporated liquid, energy consumption, and evaporation time.

Table 3: Evaporation process parameters of preliminary bench tests of the vacuum evaporator operated at -0.7 bar

No	Volume solution, L	Temperature ^{0}C	Size vacuum, ¤ bar	Volume of precipitation being riveted liquids Ll/h	Electricity consumption triple energy, kWh/L	Time evaporation, hour
1	50	60-80	-0.7	5.0	2.0	10
2	40	60-80	-0.7	4.2	2.0	10
3	30	60-80	-0.7	3.4	2.0	10

Table 3 (cont): Evaporation process parameters of preliminary bench tests of the vacuum evaporator operated at -0.7 bar

4	20	60-80	-0.7	2.3	2.0	10
5	10	60-80	-0.7	1.3	2.0	10

Table 3 shows that the solution volume varies depending on the initial solution concentration and the power of the equipment used, while the time remains constant, i.e., fixed. The initial solution is contained in the evaporator tank. The proposed technology is suitable for the disposal of brines with any salt concentration. During the study, no objective was set to analyze the concentrations of the solutions. It can also be noted that as the solution volume increases, the volume of evaporated liquid also increases, which can be useful for improving process productivity.

Energy consumption is an important indicator, which also depends on the power of the equipment used and the evaporation time. These parameters can be optimized to improve process efficiency and reduce operating costs.

Thus, the results of bench tests make it possible to evaluate the efficiency of the solution evaporation process using a vacuum evaporator and determine the optimal parameters for maximum productivity at minimum cost.

The performance of this design was improved, and the service life of the vacuum evaporator was increased by using evaporation methods at negative atmospheric pressure, which had not previously been used in existing process schemes.

A more detailed analysis of the technical processes that occur when using a mobile reverse osmosis unit allows us to identify weak technological components in the operation of each element in the design to optimize the unit's operation.

The technical and economic performance of a vacuum evaporator is determined by many factors, including efficiency, productivity, energy costs, raw materials, and equipment maintenance and repair. Field testing of the mobile unit is necessary to allow us to evaluate the actual performance and efficiency of the vacuum evaporator under various conditions and determine the optimal parameters for cost-effective operation. Accordingly, field studies were performed. The results obtained are shown in Table 4.

Table 4: Results of Field Studies with Solar (Evaporation) Trench-Type Unit (1 m^3 – 1000 L)

Month, Date	Time of day, h	Ambient air temperature, °C	Air humidity, %	Wind speed, m/s	Evaporation rate, cm/m^2	Evaporator unit capacity, L/day	Evaporator capacity L/h
25.06.	8^{00}					29,7	1,23
	12^{00}						
	14^{00}	52	Less than 10	4,5	0		
	16^{00}	48	Less than 10	2,3	0		
	18^{00}	51	Less than 10	1,8	0		
	20^{00}	38	Less than 10	0,9	1		
26.06	8^{00}	38	Less than 10	0,8	0	22,28	0,92
	10^{00}	51	Less than 10	0,8	0		
	12^{00}	56	Less than 10	0,7	1		
	14^{00}	60	Less than 10	0,8	1		
	16^{00}	57	Less than 10	1,2	0		
	18^{00}	46	Less than 10	1,7	0,5		
	20^{00}	38	Less than 10	1,7	0,5		
	22^{00}	34	Less than 10	2,4	0		
27.06	8^{00}	38	Less than 10	0,8	0,5	19,8	0,83
	10^{00}	50	Less than 10	0,8	0		
	12^{00}	56	Less than 10	2,3	0		
	14^{00}	60	Less than 10	4,5	0,5		
	16^{00}	57	Less than 10	1,8	1		
	18^{00}	45	Less than 10	1,7	0		
	20^{00}	38	Less than 10	0,7	0		
28.06	8^{00}	36	Less than 10	0,6	0	22,28	0,93
	10^{00}	47	Less than 10	0,8	0,5		
	12^{00}	52	Less than 10	1,3	0		
	14^{00}	60	Less than 10	3,5	1		
	16^{00}	55	Less than 10	4,0	1		
	18^{00}	44	Less than 10	2,2	0,5		
	20^{00}	35	Less than 10	0,9	0		

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Table 4 (cont): Results of Field Studies with Solar (Evaporation) Trench-Type Unit (1 m^3 – 1000 L)

29.06	8^{00}	36	Less than 10	0,5	0,5	19,8	0,83
	10^{00}	52	Less than 10	0,9	0		
	12^{00}	55	Less than 10	1,4	1		
	14^{00}	60	Less than 10	4,5	0,5		
	16^{00}	55	Less than 10	5	0		
	18^{00}	45	Less than 10	0,6	0		
	20^{00}	36	Less than 10	0	0		
	800	34	Less than 10	0,3	0		
	1000	39	Less than 10	1,2	0,5		
	1200	43	Less than 10	2,7	0,5		
	1400	54	Less than 10	4,7	1		
	1600	58	Less than 10	5	0,5		
	1800	42	Less than 10	1,3	0		
	2000	36	Less than 10	0,4	0		

Based on field studies conducted during the summer period, the average evaporation rate of the solar trench-type desalination (evaporation) unit was found to be approximately 3 cm/m^2 of evaporating surface per day. The average daily capacity of the solar trench-type evaporator was determined to be 8 L/day. The efficiency of the unit, at an average total solar radiation of 7000 MJ/m^2, was found to be 0.6.

Further research will focus on reducing the cost of obtaining dry residue and increasing the productivity of the solution utilizer, which will allow the equipment to be used for desalination of large quantities of water and reduce environmental risks.

4. CONCLUSIONS

This work demonstrated the viability of a mobile desalination unit with a vacuum brine evaporation module, designed to desalinate mineralized groundwater, recycle brine in a closed loop, and to produce distillate with low energy consumption. The unit combines a reverse osmosis block with a new-type vacuum evaporator, which allows the evaporation of concentrated brine without discharge into the environment. An integration of desalination and brine utilization processes within a single mobile module was achieved, which eliminates the need for separate infrastructure such as evaporation ponds. The application of a vacuum brine recovery system (vacuum evaporator) operating at a reduced pressure of -0.7 bar, allowed to lower the boiling point of brine by 20–30 °C, to reduce energy consumption by almost half compared to atmospheric evaporation, and enables operation during cold seasons. The process revealed high efficiency, the unit producing 4–4.5 L/h at 40–60 °C, whereas conventional solar evaporators yield no more than 0.9 L/h at temperatures above 25 °C — resulting in a 4–10-fold increase in efficiency.

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REFERENCES

Adewale, S., Bello, Z., Da'ana, D. A., Hahladakis, J. N., and Al-Ghouti, M. A., 2021. An overview of brine management: Emerging desalination technologies, life cycle assessment, and metal recovery methodologies. Journal of Environmental Management, 295, 113130. https://doi.org/10.1016/j.jenvman.2021.113130

Al-Marzooqi, F. A., et al., 2024. Brine management in inland desalination: Challenges and emerging solutions. Desalination and Water Treatment, 297, Pp. 35–49. https://doi.org/10.5004/dwt.2024.30129

Banerjee, P., Zaneldin, E. K., Al-Marzouqi, A. H., and Ahmed, W. K., 2025. A review of reject brine disposal, management, and construction applications. Buildings, 15(13), Pp. 2317. https://doi.org/10.3390/buildings15132317

Chen, X., Zhou, X., and Liu, W., 2022. Mobile desalination units for emergency and remote applications: Design, challenges and prospects. Desalination, 539, 116019. https://doi.org/10.1016/j.desal.2022.116019

Ghaffour, N., Bundschuh, J., Mahmoudi, H., and Goosen, M. F. A., 2019. Renewable energy-driven desalination technologies: A comprehensive review. Renewable and Sustainable Energy Reviews, 114, 109405. https://doi.org/10.1016/j.rser.2019.109405

Gude, V. G., 2022. Desalination and sustainability – An appraisal and current perspective. Renewable and Sustainable Energy Reviews, 155, 111903. https://doi.org/10.1016/j.rser.2021.111903

Karagiannis, I. C., and Soldatos, P. G., 2023. Water desalination cost literature: Review and assessment. Desalination, 573, 117115. https://doi.org/10.1016/j.desal.2023.117115

Kumari, P., Chang, Y. S., Witkamp, G.-J., Vrouwenvelder, J., Vega, L. F., and Dumée, L. F., 2024. Brine valorization through resource mining and CO_2 utilization in the Middle East – A perspective. Desalination, 582, 117598. https://doi.org/10.1016/j.desal.2024.117598

Lee, J., Park, J., and Kim, S., 2023. Advances in zero-liquid-discharge desalination: Integrating brine treatment and resource recovery. Journal of Membrane Science, 677, 121826. https://doi.org/10.1016/j.memsci.2023.121826

Mekonnen, M. M., and Hoekstra, A. Y., 2021. Sustainability: Four billion people facing severe water scarcity. Science Advances, 7(3), eaay3254. https://doi.org/10.1126/sciadv.aay3254

Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan., 2023. National Water Resources Report 2023. Astana: MEGNR. (Government report, no DOI available).

Panagopoulos, A., 2019. Brine management in desalination plants: Sustainable disposal and resource recovery. Desalination, 451, Pp. 117–134. https://doi.org/10.1016/j.desal.2018.08.013

Panagopoulos, A., Haralambous, K.-J., and Loizidou, M., 2019. Desalination brine disposal methods and treatment technologies – A review. Science of the Total Environment, 693, 133545. https://doi.org/10.1016/j.scitotenv.2019.07.351

Qiblawey, H., and Banat, F., 2020. Solar thermal desalination technologies: A review of recent developments and applications. Desalination, 495, 114659. https://doi.org/10.1016/j.desal.2020.114659

Rivero-Falcón, A., Peñate Suárez, B., and Melián-Martel, N., 2023. SWRO brine characterization and critical analysis of its industrial valorization: A case study in the Canary Islands. Water, 15(8), 1600. https://doi.org/10.3390/w15081600

Shestakov, A. L., and Mussina, G. K., 2022. Groundwater resources and water management challenges in Kazakhstan. Environmental Earth Sciences, 81, 350. https://doi.org/10.1007/s12665-022-10456-5

Subramani, A., and Jacangelo, J. G., 2021. Emerging desalination technologies for water treatment: A critical review. Water Research, 201, 117289. https://doi.org/10.1016/j.watres.2021.117289

Zhao, S., Zou, L., Mulcahy, D., and He, C., 2021. Portable desalination technologies for decentralized water supply. Journal of Water Process Engineering, 40, 101935. https://doi.org/10.1016/j.jwpe.2020.101935

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Water Conservation and Management, 10(1): 109-115.