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Seawater Desalination in the Middle East and North Africa: Environmental Impacts of Brine Discharge, Energy Use and Pathways to Sustainable Expansion in Egypt

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Abstract

Desalination has become indispensable to water security in the Middle East and North Africa (MENA), which produces almost half of the world's desalinated water. Egypt, facing a widening gap between Nile supply and demand, plans to expand seawater desalination from about 1.2–1.4 million m³ per day today to several million m³ per day within a decade. This review synthesises evidence on the environmental impacts of desalination, with emphasis on brine discharge, chemical additives, intake effects and energy use, and on management options relevant to Egypt's Mediterranean and Red Sea coasts. Globally, about 15,900 plants produce some 95 million m³ per day of fresh water and about 142 million m³ per day of brine, of which about 70% is produced in MENA. Brine, typically with roughly twice the salinity of seawater and containing antiscalants, coagulants and cleaning chemicals, can form dense plumes that affect seagrasses, corals and benthic communities near outfalls, particularly in poorly flushed embayments. Intakes cause impingement and entrainment of marine organisms, and energy use, still dominated by fossil fuels, generates substantial greenhouse-gas emissions. The review shows that most impacts can be reduced through careful site selection, subsurface intakes, diffuser outfalls, environmental monitoring, renewable energy and emerging brine-valorisation technologies, and proposes guidelines for Egypt's expansion, particularly to protect the Red Sea's coral reefs.

Keywords: *desalination; brine; reverse osmosis; marine environment; Red Sea; Mediterranean; Egypt; energy; renewable desalination; brine management*

1. Introduction

The MENA region contains about 6% of the world's population but less than 2% of its renewable fresh water. With rivers and aquifers over-exploited and climate change reducing supplies, seawater desalination has become the backbone of urban water supply in the Gulf states and an increasingly important source in North Africa. The technology has matured rapidly: reverse osmosis (RO) has displaced energy-intensive thermal processes in most new plants, and costs have fallen substantially (Elimelech & Phillip, 2011).

Egypt is now expanding desalination rapidly. Official figures indicate about 100 plants with a combined capacity of about 1.2 million m^3 per day, concentrated along the Mediterranean and Red Sea coasts and in Sinai, where conveying Nile water over long distances is impractical. A strategic plan for 2025–2050 envisages successive five-year programmes, the first of which (2025–2030) includes 23 projects with a combined capacity of about 2.66 million m^3 per day, and the prime minister announced in 2025 a target of 10 million m^3 per day within five to six years. Such expansion would make Egypt one of the largest desalination producers outside the Gulf.

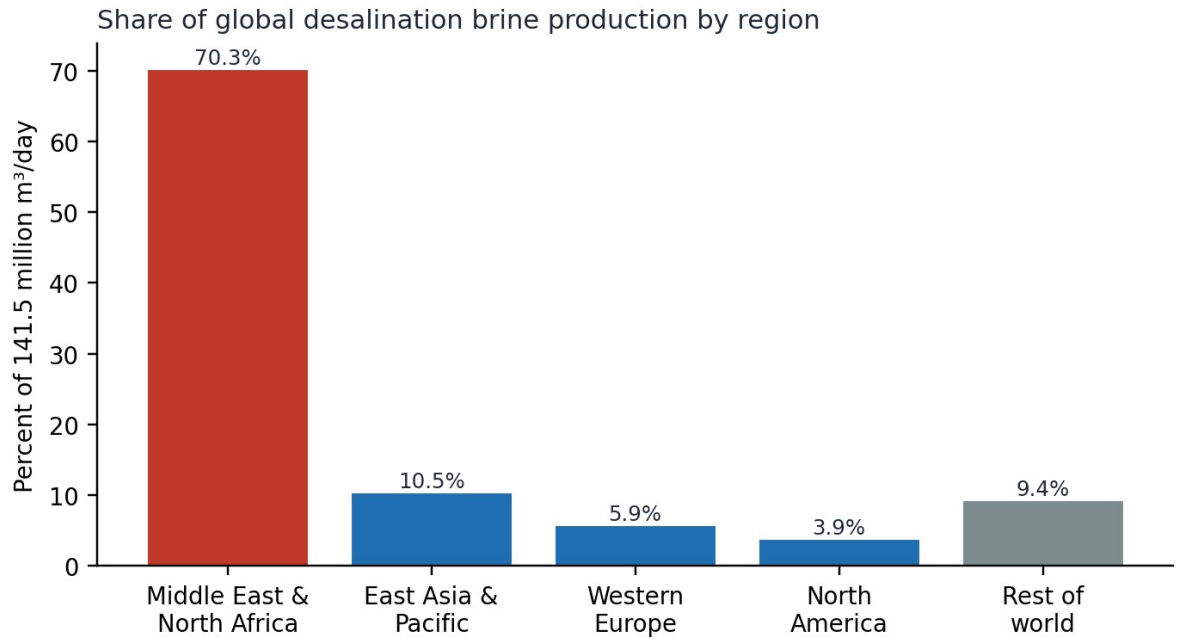
This review examines (i) the global and regional state of desalination, (ii) the environmental impacts of brine and other discharges, (iii) intake impacts and energy use, and (iv) management and policy options for sustainable expansion in Egypt.



Figure 1. Egypt's principal coastal desalination hubs on the Mediterranean (Alexandria, El Alamein–Dabaa, Marsa Matruh, El-Arish) and Red Sea (Ain Sokhna, Hurghada, Sharm El-Sheikh, Marsa Alam–Berenice), shown on a NASA Blue Marble satellite composite. The Red Sea sites lie adjacent to fringing coral reefs of global conservation importance.

2. The state of desalination and brine production

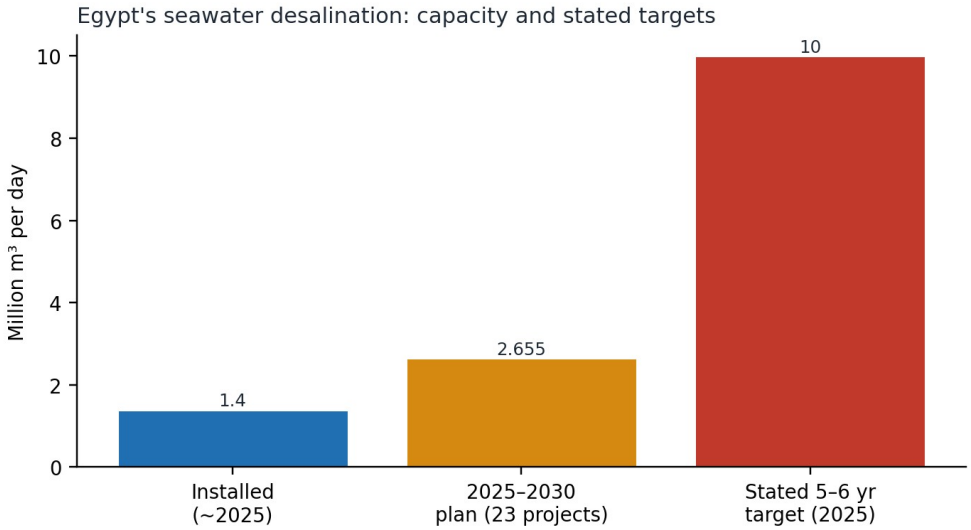
Jones et al. (2019) compiled the most comprehensive global database of desalination plants and found 15,906 operational plants producing about 95.37 million m³ per day of desalinated water, of which 48% was produced in MENA. They estimated brine production at about 141.5 million m³ per day, roughly 50% greater than earlier estimates, with MENA accounting for 70.3% of global brine. The disproportionate share reflects the region's reliance on seawater as feed and, in the Gulf, on older thermal technologies with low recovery ratios. Saudi Arabia, the United Arab Emirates, Kuwait and Qatar alone produced about 55% of the world's brine.



Source: Jones et al. (2019). 'Rest of world' is the remainder. Saudi Arabia, UAE, Kuwait and Qatar together produce 55% of global brine.

Figure 2. Share of global desalination brine production by region (Jones et al., 2019). The MENA region produces about 70% of the world's brine because of its reliance on seawater feed and thermal desalination.

The recovery ratio, the share of feedwater converted to fresh water, determines how much brine is produced. Seawater RO plants typically operate at 40–50% recovery, producing roughly 1–1.5 m³ of brine per m³ of fresh water, at a salinity of about 1.5–2 times that of seawater. Thermal plants have lower recovery but discharge larger volumes of warmer, less concentrated brine mixed with cooling water.



Sources: Egyptian Streets (Sept 2025) citing government figures; MENA news agency (2025) for the 2025–2030 plan; Ahram Online (31 Aug 2025) for the PM's target.

Figure 3. Egypt's installed seawater desalination capacity and stated targets. Sources: government figures reported by Egyptian Streets (2025); MENA News Agency (2025); Ahram Online (2025).

3. Environmental impacts of discharges

3.1 Salinity and density plumes

Because brine is denser than seawater, it tends to sink and spread along the seabed as a gravity current, particularly where outfalls discharge at the surface or in shallow water without adequate mixing. In poorly flushed embayments or semi-enclosed basins, brine can accumulate and raise salinity over the seabed for considerable distances. Benthic organisms are generally more sensitive to salinity increases than pelagic ones. The Mediterranean seagrass *Posidonia oceanica*, which forms extensive meadows of great ecological value, has been shown to be sensitive to salinity increases of only a few units above ambient, with reduced growth and increased mortality near some outfalls (Lattemann & Höpner, 2008).

The Red Sea and the Gulf are naturally saline (about 40 and up to 45 on the practical salinity scale, respectively) and have slow water exchange, which reduces their capacity to dilute brine. Coral reefs along the Egyptian Red Sea coast are already under pressure from warming, tourism and coastal development, and the cumulative effect of multiple desalination outfalls is a legitimate concern.

3.2 Temperature

Thermal desalination plants discharge brine several degrees warmer than ambient seawater. Although RO brine is only slightly warmer, co-location of RO plants with power stations can produce warm, saline plumes. Elevated temperature reduces dissolved oxygen and can stress corals that are already close to their thermal limits.

3.3 Chemical additives and metals

Pre-treatment and membrane maintenance require chemicals that end up partly in the brine: antiscalants (often phosphonates or polymers) to prevent mineral scaling, coagulants such as ferric chloride, chlorine or other biocides to control biofouling and dechlorination agents such as sodium bisulfite, which can reduce oxygen. Periodic membrane cleaning uses acids, alkalis and detergents. Thermal plants can release corrosion products including copper and nickel. Ferric-based coagulant backwash, when discharged untreated, can colour the receiving water and smother benthic habitats. Phosphonate antiscalants can act as nutrients, and residual chlorine and its by-products are toxic to marine organisms (Lattemann & Höpner, 2008; Panagopoulos et al., 2019).

3.4 Evidence of ecological effects

Field studies around desalination outfalls show that well-designed diffuser outfalls in open, well-flushed waters generally have localised effects, limited to tens to a few hundred metres, whereas surface discharges into enclosed bays or shallow lagoons can affect much larger areas (Missimer & Maliva, 2018). The ecological significance therefore depends strongly on site and design. Long-term monitoring data are scarce for North Africa, including Egypt, where most environmental impact assessments are not publicly available.

4. Intake impacts

Open seawater intakes cause impingement, in which larger organisms are trapped against screens, and entrainment, in which plankton, fish eggs and larvae are drawn into the plant and killed. These effects can be significant where intakes draw from productive nearshore waters, nursery areas or reefs. Subsurface intakes, such as beach wells, seabed infiltration galleries and horizontal directionally drilled wells, filter water through sediments, largely eliminating impingement and entrainment and improving feedwater quality; they are favoured in many guidelines but are constrained by geology and capacity (Missimer & Maliva, 2018).

5. Energy use and greenhouse-gas emissions

Modern seawater RO plants consume about 3–4 kWh per m^3 of product water, close to the thermodynamic minimum of about 1 kWh per m^3 for seawater at typical recovery; thermal processes require several times more energy (Elimelech & Phillip, 2011). At the national scale, expanding desalination to several million m^3 per day would add a substantial electricity demand: at 3.5 kWh per m^3, 10 million m^3 per day corresponds to about 35 GWh per day, or nearly 13 TWh per year. If supplied from gas-fired power, this would increase Egypt's emissions and gas consumption at a time when the country seeks to export gas and decarbonise. Coupling desalination with solar and wind power, which Egypt has in abundance, is therefore central to sustainable expansion, and the government's programme explicitly targets renewable-powered plants.

6. Brine management and valorisation

Options for brine management include ocean discharge with diffusers, which is the most common and usually lowest-cost option for coastal plants; dilution with other effluents such as power-plant cooling water or treated wastewater; deep-well injection; evaporation ponds, which are suitable only in arid inland areas with cheap land; and zero or minimal liquid discharge systems, which recover additional water and produce solid salts but are energy-intensive and costly (Panagopoulos et al., 2019).

Brine valorisation, recovering commercially valuable products such as sodium chloride, magnesium, calcium, lithium and other minerals, is an active area of research. It could turn a waste stream into a resource, and Jones et al. (2019) noted examples such as the use of brine for salt-tolerant aquaculture. Most valorisation technologies remain at pilot scale, and their economics depend on scale, energy costs and mineral prices.

7. Guidelines for sustainable expansion in Egypt

Table 1 synthesises recommendations from the literature for the planning and operation of Egypt's desalination programme.

Table 1. Recommendations for environmentally sustainable desalination expansion in Egypt

Stage	Recommendation	Rationale
Siting	Avoid enclosed bays, lagoons, seagrass meadows and coral reefs; prefer high-energy, well-flushed	Brine dilution and sensitivity of habitats vary strongly by site

	coasts	
Siting	Conduct cumulative assessments where several plants share a coastline	Multiple outfalls interact, especially on the Red Sea
Intake	Use subsurface intakes where geology allows; otherwise low-velocity screened intakes offshore	Reduces impingement and entrainment
Outfall	Discharge through offshore multiport diffusers designed by hydrodynamic modelling	Achieves rapid dilution and limits benthic plumes
Chemicals	Use low-toxicity antiscalants; treat backwash and cleaning wastes before discharge	Reduces chemical loads
Energy	Pair new plants with solar and wind power and energy-recovery devices	Reduces costs and emissions
Monitoring	Mandatory pre- and post-operation monitoring of salinity, temperature, chemistry and benthic ecology, with public reporting	Builds evidence and accountability
Regulation	Set legally binding mixing-zone salinity limits and discharge standards	Aligns with international practice
Planning	Integrate desalination with Nile, groundwater and reuse planning; prioritise drinking water and high-value uses	Desalinated water is costly; avoid using it for low-value irrigation

8. Research priorities

Priorities include: (i) baseline ecological surveys of Egyptian coasts planned for desalination, especially Red Sea reefs and Mediterranean seagrasses; (ii) field monitoring of existing plants and publication of results; (iii) toxicity studies of brine and additives on local species, including corals; (iv) regional hydrodynamic models of cumulative brine dispersion in the northern Red Sea and Gulf of Suez; (v) life-cycle and techno-economic assessments of renewable-powered desalination; and (vi) pilot projects for brine-mineral recovery.

9. Conclusions

Desalination is no longer optional for MENA; it is a pillar of water security, and Egypt's planned expansion is a rational response to its growing water gap. The environmental costs, chiefly brine discharge, chemical additives, intake mortality and energy-related emissions, are real but largely manageable with established engineering and regulatory practice. The greatest risks arise from poorly sited plants that discharge into enclosed or ecologically sensitive waters, from cumulative impacts of multiple outfalls, and from reliance on fossil energy. Egypt has the opportunity to build a desalination sector that sets a regional standard by protecting its Red Sea reefs and Mediterranean habitats, powering plants with renewable energy and making monitoring data public.

Declarations

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Data availability: No new primary data were generated. All values shown in figures and tables are taken from the cited sources. Satellite base maps use the NASA Blue Marble composite (public domain) rendered with the Basemap library.

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