Global Open Access Journal of Science

Open Access | Case Study | Aquaculture
1(2), 2025 | PP - 133 - 145

Multidisciplinary Journal ISSN - 3070-6173

Case Study Aquaculture

Desalination Brine Management via Aquaculture and Halophyte Irrigation for Fodder Production in Semi-Arid Regions

Ngosa Bwalya[1*] Samuel Appelbaum[2*], Ofer Guy[3,2], Nicola Trivellin[4] and Gideon Oron[5,6]

[1]Genius Watter Srl, Carmignano di Brenta, Padova, 35010, Italy

[2]French Associates Institute, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Kiryat Sde-Boker 8499000, Israel

[3]Ramat Negev Desert Agro-Research Center (RN-DARC), Ramat Negev Works Ltd., D.N. Halutza, 8551500, Israel

[4]Department of Industrial Engineering, University of Padua, Padova, 35131, Italy

[5]Zuckerberg Water Research Institute, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Kiryat Sde-Boker 8499000, Israel

[6]The Department of Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer-Sheva 8410500, Israel

ABSTRACT

T A brine management strategy for desalination plants is proposed that involves reusing the brine for fish farming and irrigation of halophytic plants such as Big Saltbush (Atriplex lentiformis) and Dwarf Saltwort (Salicornia bigelovii). This approach transforms a by-product of the desal-ination process into a useful input for livestock feed production, particularly relevant in the case study region of Ainabo, in Somalia's southern Sool region, where livestock rearing is the dominant livelihood. Salicornia bigelovii is a suitable crop because of its high yield, nutritional value, pal-atability to livestock, and tolerance to saline conditions.

Correspondence:

Dr. Ngosa Bwalya, Department of Industrial Engineering, University of Padua, Padova, 35131, Italy, Tel +393509448718; ORCID id: 0009-0005-2573-1154;

Dr. Samuel Appelbaum, French Associates Institute, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Kiryat Sde-Boker 8499000, Israel, Tel +972528795783; ORCID id: 0009-0003-6625-1881; Email: sappl@bgu.ac.il

Received Dates: October 31, 2025;
Accepted Date: November 17, 2025;
Published Date: November 19, 2025:

Cite this article as: Bwalya N, Appelbaum S, Guy O, Trivellin N, Oron G, Desalination Brine Management via Aquaculture and Halophyte Irrigation for Fodder Production in Semi-Arid Regions, Glob. Open Access J. Sci, 2025; 1(2):133-145.

GLOBAL OPEN ACCESS JOURNAL OF SCIENCE

A reverse osmosis desalination unit pro-ducing 50 m³ of fresh water daily and 27 m³ of brine at 20.31 mS/cm electrical conductivity (~13,000 ppm Total Dissolved Solids) would require approximately 3,600 m2 of land to fully uti-lize the brine, yielding an estimated 10,300 kg of fodder annually. The real benefit of the fodder lies in the possibility of food production from waste. Brine is also suitable for fish farming, for salt-tolerant herbivorous species such as tilapia. Integrating duckweed (Spirodela and Lemna species) into the system further provides natural water purification and additional fish nutrition. Potential environmental concerns regarding soil salinization and aquifer contamination are miti-gated through controlled irrigation practices, selection of salt-accumulating halophytes, and the option of leaching excess salts below the root zone when necessary. Together, these reuse prac-tices support a circular economy approach by turning waste streams into productive and sus-tainable resources.

Keywords: Desalination Brine, Halophytic Plants, Fish Farming, Livestock Feed, Circular Economy

INTRODUCTION

Desalination

Conventional freshwater sources are depleting and insufficient in arid regions. However, these regions often have abundant brackish groundwater or seawater. To make this water usable, its salinity must be reduced through desalination. Desalination removes salts and other impurities from saline water, making it suitable for drinking and additional uses. It typically uses brackish water which is around 16 mS/cm or less (10,000 ppm TDS), and seawater around 47 mS/cm (30,000 ppm TDS) as feed water, producing low-salt water or permeate water below 0.78 mS/cm (500 ppm TDS) and a saline by-product called brine or concentrate which is usually considered a waste product and can be 4 to 10 times higher than the feed water (Voutchkov & Kaiser, 2020e). Desalination of water has emerged as an effective alternative to traditional water softening methods in certain regions. Although costly, the critical need for fresh water drives its use. Its commercial introduction in the early 1980s marked a significant milestone in desalination. With the demand for freshwater increasing steadily, the installation of new plants and the expansion of existing ones have rapidly increased its installed capacity (Curto et al., 2021). Desalination processes produce fresh water, but their main challenges are that they are energy-intensive and produce brine that is difficult to manage and poses serious environmental challenges due to its high levels of salt and other contaminants (Voutchkov & Kaiser, 2020e).

Approaches to Brine Disposal

One approach to managing brine is through surface water discharge, where brine is released into oceans, tidal lakes, or brackish canals either directly via outfall structures, indirectly through wastewater treatment plants (WWTPs'), or disposed together with power plant cooling water (Voutchkov & Kaiser, 2020f). Another method is sanitary sewer discharge, suitable for small desalination plants that can release brine into nearby wastewater systems, provided that the volume is less than 4 m³/day and the WWTP has the capacity to process (Voutchkov & Kaiser, 2020b). Deep well injection is another option, where brine is injected into deep geological formations using wells 500-1,500 meters deep, to ensure that contaminants do not seep into potable aquifers (Voutchkov & Kaiser, 2020a). Evaporation ponds are also used, which allow water to evaporate and leave behind salt crystals that are easier to handle and dispose of (Voutchkov & Kaiser, 2020c). The zero liquid discharge (ZLD) approach aims to eliminate the need for brine disposal entirely by reducing it to purified water and dry solids through thermal or membrane brine concentrators and crystallizers. Although ZLD is costly and energy-intensive, it is gaining traction as a future trend (Voutchkov & Kaiser, 2020g).

Lastly, land application involves disposal of brine via rapid infiltration basins or crop irrigation, which is particularly suitable for areas with abundant land or salt-tolerant plants and works well in arid regions for smaller desalination plants (Voutchkov & Kaiser, 2020d). Several studies provide a comprehensive critical review and recent innovations in brine management strategies (Giwa et al., 2017; Xu et al., 2013).

By integrating an appropriate brine management system in a desalination plant, water resource usage can be optimized and associated risks can be reduced (Figure 1).

Purpose

This article delves into the development of a brine management strategy that finds productive uses for it, turning a waste product into a valuable resource and showing its feasibility as well and highlighting some considerations for implementation projects, especially in rural areas. The integrated brine reuse system addresses the environmental challenge of brine disposal by repurposing it, minimizing waste and enhancing sustainability, effectively tackling one of the two main challenges of desalination technology. This approach has far-reaching implications for sustainable water management and socioeconomic development in regions around the world dealing with water scarcity. The scope of this paper encompasses the main considerations in the development of a brine reuse system based on land application for the cultivation of halophytic crops to be used as animal feed and to be repurposed for use in valuable fish farming.

This case study examines an active solar powered brackish water reverse osmosis desalination (BWRO) facility located in Ainabo (also spelled as Aynaba, Ainaba, Aynabo or Caynabo) in the southern Sool region of Somalia. The installation was carried out by the Italian company Genius Watter as part of a UNDP-funded project that aims to provide clean water to a community of 1,000 people (Rossi, 2023).

STATE OF THE ART

The use of brine for crop irrigation is considered here because it emerges as a viable solution for the environmentally sustainable disposal of brine from desalination plants while generating value through crop cultivation. For small-scale desalination plants located in regions with low humidity, arid climates, and desert-like environments, crop irrigation stands out as the most feasible method for brine disposal. Optimal implementation of this technique relies on areas where salt-tolerant plants, also known as halophytes, naturally thrive or can be cultivated and harvested in a financially and environmentally sustainable manner (Voutchkov & Kaiser, 2020d).

The process of irrigating crops with brine is similar to traditional irrigation systems, employing methods such as sprinkler systems, drip irrigation, and direct surface application. The land area required to accommodate brine disposal through irrigation is determined by the application rate, which is a function of the salinity of the brine as well as the type of crop and soil (Voutchkov & Kaiser, 2020d). In addition, a storage facility may be necessary to store excess brine during the rainy seasons or excess brine production.

Brine as Irrigation Water

The suitability of irrigating a specific crop with brine is largely dependent on the quality of the brine, assessed through parameters such as salinity, pH, and the presence of trace metals. Evaluating the long-term impact of salt-rich brine on irrigated soil is also essential. Among these parameters, the salinity of

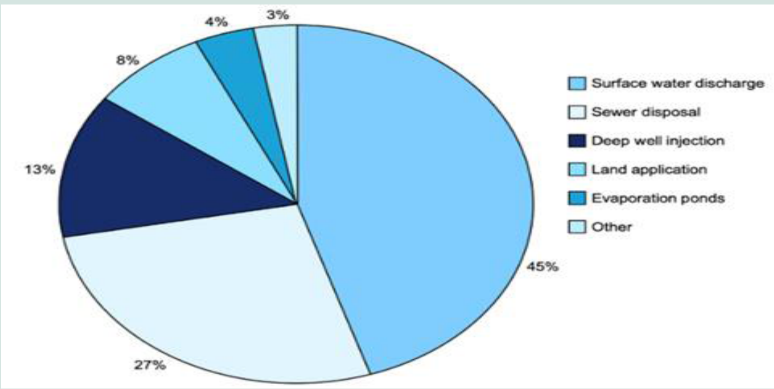

Figure 1: Current distribution of global brine management practices (Voutchkov & Kaiser, 2020e).

Table 1: Guideline for salinity (converted from TDS to EC units using 1 dS/m = 640 ppm scale) tolerance of common crops (Voutchkov & Kaiser, 2020d).

Crop	Salinity Threshold mS/cm	Salinity at Which Yield Declines by 25% mS/cm
Rye	11.41	13.75
Rapeseed (Brass. Napus)	10.94	12.89
Guar	8.75	10.23
Kenaf	8.13	10.31
Barley	7.97	12.97
Guayule	7.81	10.16
Cotton	7.66	12.5
Sugar Beet	7.03	11.25
Sorghum	6.8	8.36
Triticale	6.09	16.09
Date Palm	3.98	10.93
Mango	1.25	1.56

the brine, expressed in terms of TDS, is of particular significance. High levels of salinity in irrigation water and soil diminish the osmotic potential of the soil, reducing the absorption of water by plants. In addition, salts impede water movement through the soil, further limiting the availability of water for plants. This reduced water uptake negatively affects plant growth and productivity by hindering optimal nutrient absorption and overall development (Voutchkov & Kaiser, 2020d). Although some common crops such as sugar cane, cotton, and barley exhibit higher tolerance to salt, typically tolerating salinities of around 2,000 ppm. The salinity of the brine from desalination plants often exceeds this threshold, presenting challenges in crop selection. It is also important to note that trace metals present in the brine can also be toxic when absorbed and accumulated in the plant tissue. A pH of no more than 6 is recommended for the brine used for irrigation to prevent trace metals (Voutchkov & Kaiser, 2020e).

Crop Selection

In selecting suitable crops to be used for irrigation with desalination plant brine, most commercially grown trees, vegetables, and fruits exhibit lower salt tolerance compared to the typical TDS values found in the brine, as Table 1 shows. These salt-sensitive plants are also known as glycophytes. Saline irrigation experience reduced production yields to the point where it becomes economically not profitable once the salinity of the soil exceeds a certain threshold (Panta et al., 2014; Voutchkov & Kaiser, 2020d). Historical work of Maas and Hofman in 1977 (Maas & Hoffman, 1977) showed that crop yield decrease as the irrigation water salinity increase for various crops as illustrated in Figure 2.

In contrast, most halophytic species show enhanced growth within the salinity range of 15 mS/cm to 23 mS/cm whilst some species can survive values of EC as high as 62 mS/cm. Therefore, they represent the most viable crop option for irrigation with desalination plant brine, as they can thrive within this high salinity range while also generating financial returns that can help offset the costs associated with brine management infrastructure (Sánchez et al., 2015). Numerous types of halophytic crops are cultivated around the world for various purposes (Panta et al., 2014).

Applications of Halophytic Agriculture

Halophytes make up only about 2% of the world's plant species (Flowers & Colmer, 2008). Unlike many conventional plants that struggle and often perish in saline conditions, halophytes have evolved mechanisms to flourish in such challenging environments, offering promise as alternative crops.

Although the precise technical definition of halophytes remains elusive, with interpretations ranging from plants adapted to high salt concentrations to those capable of completing their life cycles under specific saline conditions, it is clear that these unique plants possess specialized traits, including efficient methods for using sodium and chloride ions to adjust osmotic balance, a feature lacking in most traditional crops,

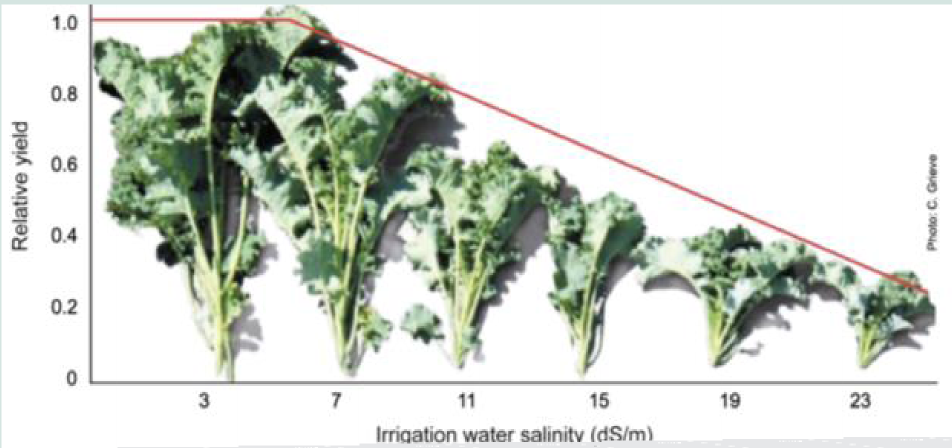

Figure 2: Salinity impact on plant yield, 1 dS/m = 640 ppm (example of Kale Plant) (Voutchkov & Kaiser, 2020e).

which rely heavily on energy-intensive processes to synthesize organic osmolytes (Flowers & Colmer, 2008). Halophytes demonstrate optimal growth within specific salinity ranges, making them suitable candidates for cultivation in regions with brackish water or seawater, such as desert or coastal areas, where conventional crops struggle to thrive. Although halophytes have long held a place in human diets, scientific interest in their potential as viable crops has risen in recent decades, fueled by research initiatives such as those conducted in Israel during the 1960s (Panta et al., 2014; Ventura et al., 2015). Numerous studies have investigated the feasibility of using halophytes for agriculture, land reclamation, floriculture, and aquaculture effluent treatment. Despite ongoing skepticism about their practicality as alternative crops, emerging markets for saline agricultural products suggest potential future demand, driven by challenges in the cultivation of traditional crops amid dwindling land and water resources. This section reports some recent advancements in harnessing halophytes for various applications, including food production, fodder cultivation, oilseed extraction, biofuel production, medicinal purposes, and phytoremediation, while also evaluating their suitability and prospects in these diverse fields (Flowers & Colmer, 2008; Panta et al., 2014).

Halophytes, or salt-tolerant plants, have recently gained recognition for their diverse applications in agriculture. In human consumption, although most food originates from a limited number of plant species like rice, maize, wheat, and potatoes, halophytes present a promising alternative in regions with saline water and soil. These unconventional crops can thrive in harsh environments where freshwater is scarce, providing valuable cash crops. For example, Distichlis palmeri, a perennial salt grass, has been a staple in the diet of native South Americans for centuries, and Quinoa, known for its superior nutritional value, has gained popularity in European markets. Other halophytes such as Pearl Millet, Atriplex triangularis, and Salicornia spp. are also being used as food sources, offering flavors and nutritional profiles that make them attractive for human consumption (Panta et al., 2014).

In animal fodder, halophytes have long served as alternative feed in saline regions, particularly in areas where seasonal feed shortages pose challenges to livestock production. Atriplex spp., commonly known as Saltbush, is extensively planted on saline land for fodder production, while other halophytes such as Kikuyu Grass and Dwarf Saltwort show promise as feed supplements. However, the high salt content and presence of antinutritional compounds in some halophytes require careful management to ensure animal health and productivity. Despite these challenges, certain livestock such as sheep, camels, and cattle can thrive on halophyte-based feed, and some halophytic grasses even improve meat quality in goats and sheep (Attia-Ismail, 2018).

Halophytes also show potential as oilseed and protein crops, with at least 50 species producing seeds that can be used for edible oil and protein production. Salicornia bigelovii, for example, has been successfully grown in various regions for oil production, producing seeds with a high oil and protein content comparable to conventional oilseed crops. The nutritional profiles of these seeds, rich in unsaturated fatty acids and other beneficial compounds, make them valuable for both human consumption and industrial applications (Glenn et al., 2013).

In the energy sector, halophytes offer a sustainable alternative to biofuel production, particularly in saline environments that are unsuitable for conventional crops. Biofuels derived from halophytic biomass, such as Tamarix chinensis and Phragmites australis, provide a renewable energy source that does not compete with food production, thus mitigating the food-versus-fuel debate. Commercial initiatives in regions like Mexico and Abu Dhabi highlight the growing interest in halophytes as a sustainable energy source (Panta et al., 2014).

Phytoremediation is another important application of halophytes, particularly for soil desalination and the remediation of polluted soils. These plants can absorb and store high levels of salt, making them effective in rehabilitating saline soils. Additionally, certain halophytes can remove heavy metals from contaminated soils through phytoextraction, offering a natural solution to environmental pollution (Panta et al., 2014).

Finally, halophytes have significant medicinal and commercial value. Many species are rich in biologically active compounds that are used in traditional medicine to treat various health conditions. For example, Ipomoea pes-caprae is known for its use in the treatment of arthritis and rheumatism, while Terminalia catappa leaves are used in Taiwan and India to treat liver diseases and other conditions. Beyond medicinal uses, halophytes have commercial applications in industries such as perfumery, rubber production, turf production, paper manufacturing, and floriculture (Panta et al., 2014).

Additional use of Brine in Fish Farming and Duckweed Cultivation

Tilapia species are among the most widely farmed, salt-tolerant herbivorous fish in the world. Originally native to Africa and the Middle East, tilapia species have gained international popularity due to their omnivorous diet, rapid growth to reach market size, tolerance to high stocking densities, and ease of reproduction. Several species, particularly Nile Tilapia (Oreochromis niloticus) and Mozambique Tilapia (Oreochromis mossambicus), have demonstrated their ability to thrive in brine from desalination systems. Their successful cultivation under such conditions has already been documented in countries such as Brazil (Sánchez et al., 2015). Since the 1970s, various strains of tilapia have been introduced into Brazil's semi-arid regions, where Nile Tilapia has proven to be the most successful and remains widely farmed there today. This clearly demonstrates the viability of brine-based tilapia farming, achieving high survival rates, sustainable yields, and efficient feed conversion comparable to conventional tilapia farming.

To further enhance the efficiency of such aquaculture systems, the integration of duckweed (Lemnacea) into the cultivation ponds offers dual functionality: it acts as a natural biofilter and serves as a supplementary feed source. Duckweed species are highly effective at removing key pollutants from wastewater, including phosphates and nitrogen, while simultaneously producing protein-rich biomass. Species such as Spirodela polyrhiza, Lemna minor, Lemna obscura, and Lemna gibba have demonstrated notable salinity tolerance, up to 10 ms/cm (Sree et al., 2015; Tkalec et al., 2001). With some specific clones that can survive in conditions up to about 24 mS/cm (Sree et al., 2015). These characteristics suggest duckweed is suitable for inclusion in moderate concentration of brine reuse systems, particularly when combined with halophyte cultivation and saline aquaculture (Wendeou et al., 2013). Its enormously rapid growth, high nutrient uptake capacity, nutritional value for both human and animal foods, and the adaptability of some strains to saline environments position duckweed as a valuable component in closed-loop, resource-efficient water reuse models (Oron et al., 2023).

MATERIALS AND METHODS

Case Study Contextualisation

This section presents a custom desalination brine management system using it to irrigate halophytic crops, which can then be utilized as a feed for livestock. Given that agriculture and livestock are central to the livelihood of the Ainabo population, comprising camels, cattle, goats, and sheep, this approach aligns well with local practices. Livestock, crucial to Somali culture and economy, includes an estimated 7.1 million camels, 5.3 million cattle, 30.9 million goats, and 13.6 million sheep, which contribute around 80% of the agricultural GDP and 45% of the national GDP (Exploring Investment Opportunities for the Livestock Sector in Somalia, 2023).

The Somali Ministry of Livestock Forestry and Range has highlighted challenges in the livestock sector due to climate change, diseases, and environmental degradation, emphasizing the need for improved fodder availability to improve livestock health and productivity. The government prioritizes the development of fodder production and presents business opportunities for local and international investors. Using BWRO brine for fodder irrigation therefore represents an innovative way to generate socio-economic benefits from this byproduct (Figure 3).

Choice of Halophyte Crops

The species of halophytic crops considered for this application are Big Saltbush (Atriplex lentiformis) and Dwarf Saltwort (Salicornia bigelovii). These crops are considered due to their high yields, nutritional value as fodder crops, and tolerance to a wide range of high salinities. Both crops are evaluated on their use as fodder crops for livestock that include cows, goats, and camels, as these are most prevalent in the Ainabo region. Several studies have been carried out on the cultivation of both Atriplex spp. and Salicornia spp. with desalination brine (Oron et al., 2023; Sánchez et al., 2015) (Figure 4).

Irrigation Area

The irrigation area required to fully use the brine produced is a function of the brine application rate, which is influenced by the salinity of the brine and the characteristics of the soil and vegetation. Application rates can vary significantly, generally falling between

Figure 3: The 6 m3/h solar powered reverse osmosis water desalination facility implemented by Genius Watter Srl in Ainabo, Somalia (Rossi, 2023).

Table 2: Daily recommended consumption of typical fodder for livestock in Ainabo provided by local pastoralists (Rossi, 2023).

Animal	Daily fodder intake kg/day
Goat	1.5
Sheep	1.5
Cow	11
Camel	5

Table 3: Fodder production

Parameter	*Atriplex Lentiformis (Big Saltbush)*	*Salicornia Bigelovii (Dwarf Saltwort)*
Land necessary to utilize all brine, ha	0.49	0.36
Fodder production, ton / ha	7.28	10.29
Number of livestock fed	26 Goats 26 Sheep 8 Camels 4 Cows	37 Goats 37 Sheep 11 Camels 5 Cows
Number of livestock fed per hectare	41 Goats 41 Sheep 13 Camels 8 Cows	58 Goats 58 Sheep 17 Camels 8 Cows

500 millimeters and 5,000 mm/year. The Atriplex spp. has an application rate of 2000 mm/year, while the Salicornia spp. has an application rate of 2,740 mm/year. To calculate the irrigation area, a simplified methodology (Voutchkov & Kaiser, 2020d) is adopted as shown below;

$$A_{irr} = \frac{Q_{b,tot}}{R_{app}}$$

Where:

- A_{irr} is the irrigation area, m^2
- $Q_{b,tot}$ is the total yearly brine production, m^3/ year
- R_{app} is the brine application rate, m / year

If brine cannot be used for irrigation for an extended period, it is essential to have storage facilities as a backup. Typically, concrete, plastic or lined ponds are constructed for this purpose. The storage capacity required depends on the duration for which the plant will produce brine without irrigation. Storage is recommended for two to five days to ensure operational flexibility of the irrigation system. However, if the site is expected to experience high rainfall, the storage capacity should be increased accordingly. An additional 30 % of land can be considered for the service paths, crop storage zones, and brine storage facilities.

Crop Production

The dry weight biomass yield of halophyte crops can vary at different salinity levels. There is no precise

Figure 4 (A) Flood-irrigated with seawater Salicornia bigelovii in Puerto Penasco, Mexico (B) first-year growth of Atriplex lentiformis irrigated with reverse-osmosis brine in drainage lysime-ter plots in Marana, Arizona (Glenn et al., 2013).

consensus on the yield of these halophyte crops as a function of irrigation water salinity, because studies on the use of brackish water desalination brine to irrigate Atriplex spp. and Salicornia spp. are recent and limited. In addition, many factors beyond the scope of this study, such as climate, soil properties, and underground water characteristics, influence the yield. However, the average values for Atriplex spp. and for Salicornia spp. is about 20 tonnes and 25 tonnes per hectare per year of total biomass dry matter, respectively, as presented in some studies (Hamed et al., 2014) are used to provide a reasonable approximation.

It is important to note that the fraction of biomass usable as fodder depends on the plant species. For Atriplex spp., only about 57% of the biomass is typically used as fodder due to its hard, woody stems (Sánchez et al., 2015). In contrast, nearly 100 % of Salicornia spp. biomass, which is leafier and softer, can be consumed by livestock (Glenn et al., 2013).

Livestock cannot live solely on a halophytic fodder diet due to its relatively lower palatability, unfavorable chemical composition (high mineral ash content and presence of plant secondary metabolites), and lower energy content compared to conventional fodder. However, several experiments have shown that the best weight gains for livestock are observed when halophytic fodder constitutes between 38.3 % and 64.6 % of their total diet (Sánchez et al., 2015). For this analysis, we consider an average inclusion ratio of 51.5%. (Table 2)

RESULTS

Production of Animal Feed

The total annual brine production is around 9790 m3/year with a nominal EC value of 20.31 mS/cm. As we have considered an inclusion rate of 51.5 %, it is important to note that the total fodder produced contributes to about half of the yearly diet of the livestock. (Table 3)

As a pilot project, we propose cultivating Salicornia bigelovii as a food supplement for livestock, particularly sheep and goats. This crop is chosen because of its high biomass yield, ability to feed more livestock, ease of establishment in degraded soils, low land requirements, and high palatability. Additionally, there are readily available commercial options for Salicornia bigelovii making it a practical choice. (Figures 5, 6)

Economic Value of Salicornia Cultivation

An economic analysis was performed using data from a recent study (Oron et al., 2023). Although different scenarios may use alternative values, the study offers an estimation of economic expectations based on local data and evaluations from other research (Lyra et al., 2020). The analysis shows that the net return for Salicornia cultivation is approximately 4.65 cents/m2 per year. Specifically, in the context of Ainabo, this equates to about €167.4 per year for the land required

Figure 5: Visual representation of irrigation land in comparison to the desalination plant area at Ainabo, Somalia.

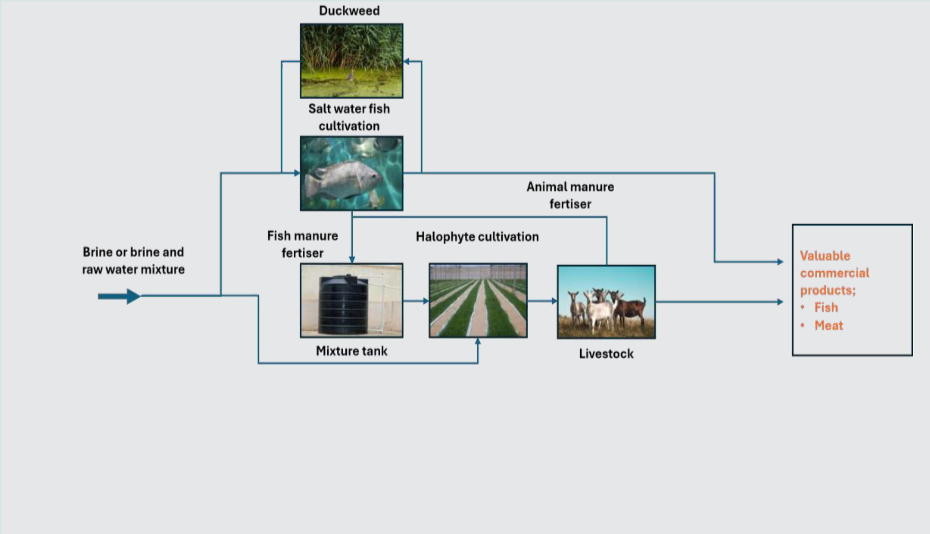

Figure 6: Illustration of the integrated brine reuse scheme proposed at Ainabo, Somalia.

to manage the total brine.

Although this is a relatively low monetary return, it is important to consider that this scheme uses waste resources and helps avoid potential regulatory infringements. Furthermore, the socio-economic value of involving local communities in the operation and maintenance of the project offers additional incentives. This inclusion not only fosters local employment, but also promotes community participation and skill development, thereby improving the overall sustainability and acceptance of the initiative.

DISCUSSION

The proposed brine reuse system demonstrated promising potential for sustainable resource management in arid and semi-arid environments. The use of desalination brine for irrigating halophytic plants such as Atriplex lentiformis and Salicornia bigelovii resulted in healthy biomass production under high-salinity conditions, confirming their suitability for fodder production in regions with limited freshwater resources. Similar findings have been reported in other saline agriculture systems, where halophytes effectively utilize saline effluents while improving soil structure and nutrient balance (Feng et al., 2013; Qadir et al., 2007).

The integration of aquaculture using brine, particularly with salt-tolerant fish such as Oreochromis niloticus and O. mossambicus, offers an additional layer of productivity. Previous studies conducted in the Brazilian semi-arid region have shown that tilapia can thrive in saline environments, achieving growth and survival rates comparable to conventional freshwater systems. Incorporating duckweed (Spirodela polyrhiza and Lemna spp.) into these aquaculture systems enhances nutrient removal, improves water quality, and provides supplementary feed, contributing to a closed-loop system that minimizes waste discharge.

A key environmental consideration in saline water reuse systems is the potential for soil and groundwater salinization. However, the risk is context-dependent. In areas such as southern Somalia, where natural desert conditions already produce saline soils and no potable aquifer is present, the risk of aquifer contamination is minimal. Furthermore, halophyte crops actively uptake and sequester salts within their biomass, removing a portion of the salt load from the system upon harvest (Flowers & Colmer, 2008). To prevent salt accumulation in the root zone, controlled leaching irrigation practices can be applied by supplying 20 to 40 percent more water than plant uptake requirements. This excess water helps transport dissolved salts below the active root layer, particularly in sandy or well-drained soils (Hanson et al., 2008).

CONCLUSIONS

Freshwater scarcity affects billions worldwide and continues to worsen due to climate change, population growth, and unsustainable water extraction. Desalination offers an increasingly reliable important source of freshwater in regions lacking conventional supplies however, managing the resulting brine remains a major environmental challenge. This work proposes a conceptual brine-reuse model in which halophyte crops and aquaculture systems convert desalination waste into productive outputs that support livestock feeding and food security in semi-arid regions.

The proposed model demonstrates the theoretical feasibility of integrating brine irrigation, halophyte cultivation, and fish farming in rural settings such as Ainabo, Somalia. Because the current work is based on literature data and general environmental assumptions, further steps are necessary before real-world implementation. These include collecting local soil, water, and brine chemistry data evaluating, ion composition and trace elements such as boron, monitoring potential salt accumulation over time; and determining leaching requirements and long-term soil sustainability under continuous saline irrigation. Field trials, soil EC profiling, and leachate monitoring will be essential to quantify environmental risks and validate crop yield estimates.

Economically, the current evaluation is preliminary and relies on secondary data. A more detailed assessment including local market prices, labor costs, comparative analysis with alternative disposal methods, and sensitivity analysis will be required to fully understand feasibility and benefit margins.

Therefore, this study should be regarded as a conceptual framework rather than an operational blueprint. It establishes a basis for future applied research, field validation, and system optimization. Ultimately, integrated brine reuse through halophytes, aquaculture, and wastewater-purifying duckweed offers a promising pathway toward improved water and food security, reduced environmental burden, and a circular economy in resource-constrained regions.

Author Contributions: Conceptualization, N.T and N.B.; methodology, S.A and N.B.; software, N.B.; validation, S.A., O.G. and G.O.; formal analysis, S.A and N.B.; investigation, N.B and S.A.; resources, N.B.; data curation, N.B.; writing—original draft preparation, N.B.; writing—review and editing, S.A.; visualization, N.B.; supervision, S.A, O.G. and G.O.; project administration, N.T.; funding acquisition, N.T. All authors have read and agreed to the published version of the manuscript.

FUNDING: This research received no external funding.

INSTITUTIONAL REVIEW BOARD STATEMENT: Not applicable.

INFORMED CONSENT STATEMENT: Not applicable.

DATA AVAILABILITY STATEMENT: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

ACKNOWLEDGMENTS: This project research was conducted as part of the Energy Engineering Master's Degree Program at the Department of Industrial Engineering at the University of Padua and was completed in collaboration with Genius Watter Srl, an Italian company specializing in clean water production through innovative reverse osmosis desalination plants powered by photovoltaic solar energy. The Technical Department of Genius Watter Srl headquarters in Carmignano di Brenta, Italy is focused on the research and development of photovoltaic powered reverse osmosis water desalination facilities with an integrated brine reuse system for remote applications.

CONFLICTS OF INTEREST: The authors declare no conflicts of interest.

DISCLAIMER/PUBLISHER'S NOTE: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s).

ABBREVIATIONS

The following abbreviations are used in this manuscript:

BWRO: Brackish Water Reverse Osmosis

EC: Electrical Conductivity

GDP: Gross Domestic Product

TDS: Total Dissolved Solids

UNDP: United Nations Development Program

USEPA: United States Environmental Protection Agency

WWTP: Wastewater Treatment Plant

ZLD: Zero Liquid Discharge

REFERENCES

- Attia-Ismail, S. A. (2018). Halophytes as Forages. In R. L. Edvan & L. R. Bezerra (Eds.), *New Perspectives in Forage Crops*. InTech. https://doi.org/10.5772/intechopen.69616
- Curto, D., Franzitta, V., & Guercio, A. (2021). A Review of the Water Desalination Technologies. *Applied Sciences*, *11*(2), 670. https://doi.org/10.3390/app11020670
- *Exploring investment opportunities for the livestock sector in Somalia*. (2023, August 17). https://www.ilri.org/news/exploring-investment-opportunities-livestock-sector-somalia
- Feng, L., Ji, B., & Su, B. (2013). Economic value and exploiting approaches of sea asparagus, a seawater-irrigated vegetable. *Agricultural Sciences*, *4*(9), 40–44. https://doi.org/10.4236/as.2013.49B007
- Flowers, T. J., & Colmer, T. D. (2008). Salinity tolerance in halophytes. *New Phytologist*, *179*(4), 945–963. https://doi.org/10.1111/j.1469-8137.2008.02531.x
- Giwa, A., Dufour, V., Al Marzooqi, F., Al Kaabi, M., & Hasan, S. W. (2017). Brine management methods: Recent innovations and current status. *Desalination*, *407*, 1–23. https://doi.org/10.1016/j.desal.2016.12.008
- Glenn, E. P., Anday, T., Chaturvedi, R., Martinez-Garcia, R., Pearlstein, S., Soliz, D., Nelson, S. G., & Felger, R. S. (2013). Three halophytes for saline-water agriculture: An oilseed, a forage and a grain crop. *Environmental and Experimental Botany*, *92*, 110–121. https://doi.org/10.1016/j.envexpbot.2012.05.002
- Hamed, K. B., Magné, C., & Abdelly, C. (2014). From Halophyte Research to Halophytes Farming. In M. A. Khan, B. Böer, M. Öztürk, T. Z. Al Abdessalaam, M. Clüsener-Godt, & B. Gul (Eds.), *Sabkha Ecosystems: Volume IV: Cash Crop Halophyte and Biodiversity Conservation* (Vol. 47, pp. 135–142). Springer Netherlands. https://doi.org/10.1007/978-94-007-7411-7_9
- Hanson, B., Hopmans, J., & Simunek, J., Jirka. (2008). Leaching with Subsurface Drip Irrigation under Saline, Shallow Groundwater Conditions. *Vadose Zone Journal - VADOSE ZONE J*, *7*. https://doi.org/10.2136/vzj2007.0053
- Lyra, D. A., Ismail, S., & Brown, J. J. (2020). Crop Potential of Six Salicornia bigelovii Populations Under Two Salinity Water Treatments Cultivated in a Desert Environment: A Field Study. In A. Hirich, R. Choukr-Allah, & R. Ragab (Eds.), *Emerging Research in Alternative Crops* (Vol. 58, pp. 313–333). Springer International Publishing. https://doi.org/10.1007/978-3-319-90472-6_14
- Maas, E. V., & Hoffman, G. J. (1977). Crop Salt Tolerance—Current Assessment. *Journal of the Irrigation and Drainage Division*, *103*(2), 115–134. https://doi.org/10.1061/JRCEA4.0001137
- Oron, G., Appelbaum, S., & Guy, O. (2023). Reuse of brine from inland desalination plants with duckweed, fish and halophytes toward increased food production and improved environmental control. *Desalination*, *549*, 116317. https://doi.org/10.1016/j.desal.2022.116317
- Panta, S., Flowers, T., Lane, P., Doyle, R., Haros, G., & Shabala, S. (2014). Halophyte agriculture: Success stories. *Environmental and Experimental Botany*, *107*, 71–83. https://doi.org/10.1016/j.envexpbot.2014.05.006
- Qadir, M., Oster, J. D., Schubert, S., Noble, A. D., & Sahrawat, K. L. (2007). Phytoremediation of Sodic and Saline□ Sodic Soils. In *Advances in Agronomy* (Vol. 96, pp. 197–247). Academic Press. https://doi.org/10.1016/S0065-2113(07)96006-X
- Rossi, M. (2023). *Engineer at Genius Watter Srl*.
- Sánchez, A. S., Nogueira, I. B. R., & Kalid, R. A. (2015). Uses of the reject brine from inland desalination for fish farming, Spirulina cultivation, and irrigation of forage shrub and crops. *Desalination*, *364*, 96–107. https://doi.org/10.1016/j.desal.2015.01.034
- Sree, K. S., Adelmann, K., Garcia, C., Lam, E., & Appenroth, K.-J. (2015). Natural variance in salt tolerance and induction of starch accumulation in duckweeds. *Planta*, *241*(6), 1395–1404. https://doi.org/10.1007/s00425-015-2264-x
- Tkalec, M., Mlinarec, J., Vidaković-Cifrek, Ž., Jelenčić, B., & Regula, I. (2001). The effect of salinity and osmotic stress on duckweed Lemna minor L. *Acta Botanica Croatica*, *60*, 237–244.
- Ventura, Y., Eshel, A., Pasternak, D., & Sagi, M. (2015). The development of halophyte-based agriculture: Past and present. *Annals of Botany*, *115*(3), 529–540. https://doi.org/10.1093/aob/mcu173

- Voutchkov, N., & Kaiser, G. N. (2020a). Deep well injection. In *Management of Concentrate from Desalination Plants* (pp. 137–149). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00006-3
- Voutchkov, N., & Kaiser, G. N. (2020b). Discharge to sanitary sewer. In *Management of Concentrate from Desalination Plants* (pp. 131–136). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00005-1
- Voutchkov, N., & Kaiser, G. N. (2020c). Evaporation ponds. In *Management of Concentrate from Desalination Plants* (pp. 173–186). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00008-7
- Voutchkov, N., & Kaiser, G. N. (2020d). Land application. In *Management of Concentrate from Desalination Plants* (pp. 151–172). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00007-5
- Voutchkov, N., & Kaiser, G. N. (2020e). *Management of concentrate from desalination plants*. Elsevier.
- Voutchkov, N., & Kaiser, G. N. (2020f). Surface water discharge of concentrate. In *Management of Concentrate from Desalination Plants* (pp. 25–77). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00003-8
- Voutchkov, N., & Kaiser, G. N. (2020g). Zero-liquid discharge concentrate disposal systems. In *Management of Concentrate from Desalination Plants* (pp. 187–208). Elsevier. https://doi.org/10.1016/B978-0-12-818045-7.00009-9
- Wendeou, S. P. H., Aina, M. P., Crapper, M., Adjovi, E., & Mama, D. (2013). Influence of Salinity on Duckweed Growth and Duckweed Based Wastewater Treatment System. *Journal of Water Resource and Protection*, *5*(10), Article 10. https://doi.org/10.4236/jwarp.2013.510103
- Xu, P., Cath, T. Y., Robertson, A. P., Reinhard, M., Leckie, J. O., & Drewes, J. E. (2013). Critical Review of Desalination Concentrate Management, Treatment and Beneficial Use. *Environmental Engineering Science*, *30*(8), 502–514. https://doi.org/10.1089/ees.2012.0348

©2025 Bwalya N, Appelbaum S, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License 4.0 International License.

Cite this article as: Bwalya N, Appelbaum S, Guy O, Trivellin N, Oron G, Desalination Brine Management via Aquaculture and Halophyte Irrigation for Fodder Production in Semi-Arid Regions, Glob. Open Access J. Sci, 2025; 1(2):133-145 ..