MINIMIZING THE ENVIRONMENTAL IMPACT OF SEA BRINE DISPOSAL BY COUPLING DESALINATION PLANTS WITH SOLAR SALTWORKS: A CASE STUDY FOR GREECE

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EXTENDED ABSTRACT

The explosive increase in world population, along with the unusual socio-economic development and the climate change have all led to an increased water demand, making water shortage one of the greatest problems of modern society. Countries such as Greece, Saudi Arabia or Tunisia face serious water shortage issues. Specifically for Greece, some islands face more severe water shortage issues than the mainland. This is related to the local climate, the islands geomorphology and the steep increase in population during the summer months when the water shortage is more extreme due to the high temperatures.

In order to deal with water shortage problems, Greece has resorted to solutions such as transporting water by ships from the mainland to the islands, a practice that is expensive, energy-intensive and unsustainable. The promising process of desalination of brackish or sea water to supply the country with potable water is suitable for providing desalinated water to arid regions such as the Greek islands.

The major concern for desalination systems lies in the extensive brine discharge that may heavily affect marine biota. Even though the concentrated brine contains natural marine ingredients, its high specific weight causes it to sink to the sea floor and negatively impacts the flora and fauna associated with sea-grasses. To avoid this impact, we explore the option of directing the desalination effluent to a solar saltworks for brine concentration and ultimate salt production in order to achieve a zero discharge desalination plant

In this context, we conducted a survey on the locations of possible desalination plants and solar saltworks in Greece and mapped the data in a Geographic Information System (GIS). This was done in order to assess the distances between desalination plants and solar saltworks and to investigate the economic potential of transferring the highly concentrated desalination plant effluent to the solar saltworks, so that the disposal of brine in the sea is avoided. Our analysis showed that brine transfer by trucks is prohibitively expensive and that efforts should be directed into developing a more efficient technology that will result in the production of only a fraction of the brine that is produced from our systems today, in order to make the zero discharge plant economically feasible.

KEYWORDS: solar saltworks, desalination plants, sea brine disposal, GIS tools

1. INTRODUCTION

1.1 The water shortage problem in Greece

Countries such as Greece, Saudi Arabia or Tunisia face serious water shortage issues [1]. Increased water demand due to economic growth, irrigation needs, declining precipitation levels and over-abstraction of groundwater are all factors that create fresh water shortage problems in many regions of Greece and specifically in the Aegean

Archipelago islands [2]. Particularly during the summer period, the population of the islands may be up to five times more than the winter, thus resulting in intense water shortage problems. This is true due to the following reasons:

- In some islands of the South Aegean and the Cyclades, the average annual precipitation height is less than half the corresponding value for mainland Greece, which is approximately 700 mm.
- During the summer months, most islands experience a heavy seasonal rise in population due to tourism, a higher water demand due to increased temperatures and very limited precipitation that amounts to about 7% of their total annual rainfall.
- Most Greek islands and other arid coastal areas have a particularly bold relief with steep slopes, hills and mountains and little forest or green coverage. As a result, surface flows move with great momentum in a torrent-like fashion, cannot be withheld by vegetation—as it is very limited—and cascade their way down to the sea, with only a small percentage of that flow recharging groundwater and aquifers.
- Aquifers are usually small and connected to the sea. Intense groundwater pumping to cover fresh water shortage in the islands results in the drop of the water level, which is followed by the influx of seawater, making groundwater brackish and essentially destroying the aquifer.

On the other hand, it is clear that the development and the quality of life in the arid coastal regions of Greece with tourist development depend mainly on the sufficiency of water resources. Water resources are quite limited, thus restraining the economic development of the local societies. To face increased potable water requirements, more than 1,000,000 m^3 of clean water are transported annually to these areas at a cost sometimes approaching the value of 8 euros/m^3 [3]. Even if one ignores the high price of transporting water by ships, it is also energy-intensive; thus unsustainable in the long term. On the other hand, wind- or solar-powered desalination plants are suitable for providing desalinated water to communities where renewable energy sources such as wind or solar radiation abounds, as is the case in the Greek islands [4], or other areas in the Mediterranean with similar characteristics [5]. However, in many cases, the construction of desalination infrastructure projects is avoided, because of social reactions surrounding the potential environmental impacts of desalination plants. Thus, water continues to be transported by ships, the cost is very high and burdens the State, while at the same time, the local communities suffer from the consequences of the unreliability of water transport.

This paper attempts to show how important proper design of operations is and how current practices need considerable improvement, in order to overcome the negative environmental impacts of desalination plants, thus making desalination the number one choice of feasible and environmentally friendly water production in the arid regions of the Mediterranean.

1.2 The environmental impacts of desalination plants and mitigation strategies

Recently, there has been a lot of discussion in the literature on the environmental impact of desalination plants, especially for those in Spain, since the Water National Plan of the country included desalination as one of the technologies for supplying water for human consumption, tourist uses, as well as agricultural or industrial consumption [6]. European legislation makes an Environmental Impact Assessment (EIA) mandatory for desalination plants producing over 5,000 m^3 of water/day.

Environmental impacts include the indirect impact due to the need to increased demand for electricity production for desalination plants. Fossil-fuel powered desalination plants have environmental effects related to the emission of green-house gases or other pollutants associated with power generation [7]. This negative impact could be overcome if renewable energy sources (RESs), such as wind turbines, solar panels, geothermal energy, photovoltaic units, hydrodynamic energy etc. are used instead of fossil fuels. Luckily, wind and solar energy are usually abundant in the coastal Mediterranean areas [3]. Such plants that rely exclusively on RESs have already been built and operate successfully in Greece.

A direct impact of desalination plants today is that on the marine environment, as a result of returning the concentrated brine to the sea, which is at a relatively high temperature. Einav et al. [8] indicate that the extent of vulnerability of the marine environment to salinity differs from place to place. It is measured by the nature of the marine habitat: coral reef, rocky beach or sandy surfaces and by the origin of the surrounding organism. Although data from monitoring the dispersion and the effects of the hyper-saline effluents originated by desalination plants are very scarce, it is now documented that, especially in the Mediterranean region, the Posidonia seagrass (*Posidonia oceanica,* endemic plant in the Mediterranean sea) habitat is very sensitive to high salinities derived from brine discharge [6], [9], [10]. If desalination brine is not disposed of to the sea at all, then this impact can also be overcome. The idea of constructing a zero effluent desalination plant has been suggested before [11]. In this paper, we evaluate the option of transporting the brine from desalination plants to saltworks, thus operating existing desalination plants with zero effluent.

Another impact on the marine environment is realized when different products used in chemical cleaning of membranes and pretreatment cleaning are disposed of in the sea. These products are all contained in the desalination brine; therefore, potential negative impacts from disposing of the brine in the sea are avoided if the brine is collected and transported to saltworks. Naturally, if the salt produced is directed for human consumption, appropriate measures should be taken.

Noise pollution around the desalination plants is also an important impact [10]. High pressure pumps and energy recovery systems, such as turbines, produce significant level of noise—in some cases, over 90 dB. Aside from that, the adverse effect on land use cannot be underestimated, as these plants are located on coastal areas that may have tourist interest. Recently, a floating autonomous environmentally friendly and efficient desalination unit was developed by researchers of the Aegean University and operates in the Aegean sea [12]**.** These small plants, not only rely on RES to function, but have the added advantage of not being located on the coast, but floating deeper in the sea; this way the impacts related to noise pollution and adverse effect of land use could be overcome.

2. MATERIALS AND METHODS

In order to assess the possibility of transferring brine produced by desalination plants to solar saltworks to produce salt, we collected data regarding the locations of both desalination plants and solar saltworks in Greece [13]. Solar saltworks, both natural and artificial, have existed in Greece for a very long time and are important wetland ecosystems [14], [15]. We prepared a list of potential locations where new desalination plants could be built based on extensive discussions with local government officials, and imported this information in a Geographic Information System (GIS). Mapping the data in a GIS, facilitated our analysis relevant to plant and saltworks location, their respective distance from each other, their proximity to ports or major land transportation routes, as well as the different modes of transportation that need to be used in order to couple them. The solar saltwoks (blue circles) and the desalination plants (green circles) that operate in Greece are mapped in Figure 1, as well as the desalination units that we suggest to have constructed (pins). In Figure 1, we also show the suggested routes that could be followed for the transport of brine from each desalination plant (origin) to the closest, or most easily accessible saltworks unit (destination). Some routes that connect island units are serviced solely by ships, while others are done by a combination of ship and truck transfer. The origin-destination pairs and corresponding modes of transportation for each pair are listed in Table 1.

Naturally, one of the most important factors in assessing the feasibility of operating a zero discharge seawater desalination plant system is cost. In this case, the largest cost is incurred in transporting the brine from desalination plants to saltworks. In this paper, we make a rough estimate of that amount adding the cost of transporting brine by ships and/or special trucks. We acquired these figures either by the literature, or from personal interviews with transportation companies. Specifically, for the cost of brine transporting by truck, we obtained quotes from special truck companies that transfer liquids. The average price is 0.24€/km/-m^3 of brine and we multiply it by the distance traveled to estimate the truck transportation cost, as shown in Table 1. Regarding the transportation by ship, we do not have a price quote per km, but two prices per m^3 of brine: one for transporting brine from island to island (estimated at 4.8€/m^3), and one from the mainland to the islands (8.21€/m^3) [16]. The latter cost is also used for the calculation of brine transportation from Irakleio, Crete to Milos island. Table 1 tabulates all costs for all origin-destination pairs.

RESULTS AND DISCUSSION

The cost of operating a zero discharge desalination plant is partially credited by the profits realized from selling the extra salt produced by the desalination effluent brine. Also, with desalination plants becoming zero effluent, there is no need for the construction of a metallic non-corrosive pipe (50m to 1000m in length) and diffuser that discharges the effluent brine deep in the sea. An indicative cost of this pipe is estimated at 1,500€/m, or a total of several thousand euros. Needless to say, the largest savings are realized when, with the construction of the desalination plants, the coastal arid sites can become autonomous and will not need to have water transported there. From 2004 to 2006, the Greek government has paid for the transportation of water to the arid islands that face serious water-shortage issues approximately 25.5€ million, while over 9.5€ million were spent for water transportation in 2006 alone. Just for comparison purposes, it is estimated that the 25.5€ million that the government has spent in 3 years for transporting water could be used for the construction of 15 seawater desalination units with a capacity of 30,000 m^3/day in total, with an indicative water production cost of 0.4€/m^3 [16].

Even when transported by ship and taking the most inexpensive of the two cases, it is still going to cost us 4.8€/m^3 for the brine transport, which compares to about 0.4€/m^3 for the production of desalinated water. So, in the best case scenario and given that for every 1 liter of desalinated water produced, we produce another liter of brine, the proper disposal of brine to a saltworks still costs about 10 times more than the production of desalinated water. Therefore, to balance out the cost of the useful product (water) with the cost of safe disposal of the process waste (brine), we need to ensure that the technology is such that brine is produced at a rate of 10 to 1, i.e. for every 10 liters of desalinated water produced, we make only 1 liter of brine. This analysis is valid only under the assumption that the water is produced at the location in which it is consumed, i.e. there is no need to transfer the desalinated water. Naturally, this is the preferred practice, as transporting water may give rise to hygienic issues and water quality deterioration due to its transport.

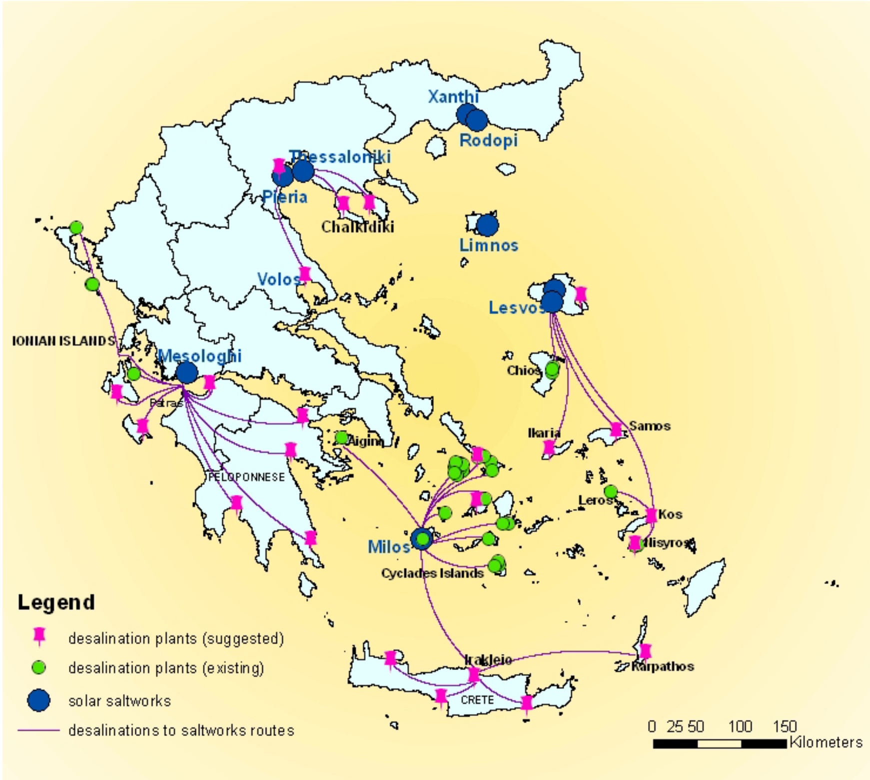

Figure 1. GIS map of Greece with desalination plants (suggested and existing), solar saltworks and routes for the transportation of brine

When looking at the data from Table 1, we see that the cost of transporting brine by truck is prohibitively expensive. Since we have a per-km rate that is pretty high, locations that are a few hundred kilometers away can add up to almost 90€/m^3 of brine transported. If one compares this cost to the cost of transporting water (the very process that we find unsustainable and we want to avoid) of less than 8€/m^3, we see that such a transfer is even more unsustainable and expensive.

The question that is relevant here is how much brine is produced for the production of 1 m^3 of desalinated water. Currently, using today's technology, this number is relatively high. Processes vary in efficiency, but usually produce about 1 m^3 of brine for every 1 m^3 of desalinated water. In order to make desalination an environmentally friendly process, we should re-design the process, using the minimization of the effluent brine as a design criterion. This way, we will ensure that the proper technology is employed in order to produce a design that actually makes less effluent brine, since it is expensive to transfer to a saltworks and dispose of it without any environmental impacts.

Table 1. Routes and costs of transporting brine from desalination units to solar saltworks

Desalination plant locations (origin)	Solar saltworks locations (destination)	By ship	By truck	Distance by truck (km)	Cost for transporting brine by ship (€/m^3)	Cost for transporting brine by truck (€/m^3)	Total Cost (€/m^3)
Chios island	Lesvos island	[			4.8		4.8
Samos island	Lesvos island	[			4.8		4.8
Ikaria island	Lesvos island	[			4.8		4.8
Kos island	Lesvos island	[			4.8		4.8
Nisyros island	Lesvos island	[			4.8		4.8
Leros island	Lesvos island	[			4.8		4.8
All Cyclades island locations	Milos island	[			4.8		4.8
North Crete (Irakleio)	Milos island	[			8.21		8.21
North Crete (Chania)	Milos island via Irakleio	[	[	134	8.21	32.16	40.37
South Crete (Ierapetra)	Milos island via Irakleio	[	[	105	8.21	25.2	33.41
South Crete (Sitia)	Milos island via Irakleio	[	[	143	8.21	34.32	42.53
Karpathos island	Milos island via Irakleio	[			13		13
Patra	Mesologhi		[	44		10.56	10.56
Nayplio	Mesologhi		[	220		52.8	52.8
Monemvasia	Mesologhi		[	372		89.28	**89.28**
Methoni	Mesologhi		[	244		58.56	58.56
Kalamata	Mesologhi		[	259		62.16	62.16
All Ionian island locations	Mesologhi via Patra	[	[	44	4.8	10.56	15.36
Volos	Pieria		[	200		48	48
Kassandra, Chalkidiki	Thessaloniki		[	86		20.64	20.64
Sithonia, Chalkidiki	Thessaloniki		[	125		30	30

4. CONCLUSIONS

Water shortage has become one of the greatest problems of modern society mostly due to the explosive increase in population, along with the socio-economic development and the climate change. In order to deal with water shortage problems, Greece has resorted to solutions such as transporting water by ships from the mainland to the islands that face a more serious water shortage problem, a practice that is expensive, energy-intensive and unsustainable. The promising process of seawater desalination to supply the country with potable water is suitable for providing desalinated water to arid coastal regions in Greece and other Mediterranean countries that face similar issues. Desalination systems, however, produce concentrated brine that, when disposed of in the sea, may heavily affect marine biota. To avoid this impact, we explore the option of directing the desalination effluent to a solar saltworks for brine concentration and ultimate salt production in order to achieve a zero discharge desalination plant. A survey was conducted on the locations of possible desalination plants and solar saltworks in Greece and mapped the data in a GIS, in order to assess the distances between desalination plants and solar saltworks and to investigate the economic potential of transferring effluent brine to solar saltworks, so that disposal of brine in the sea is avoided. Our analysis showed that brine transfer by trucks is prohibitively expensive and that efforts should be directed into developing a more efficient technology that will result in the production of only a fraction of the brine that is produced from our systems today, in order to make the zero discharge plant economically feasible.

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