Investment efficiency of floating platforms desalination technology in Egypt

Dalia E. Abozaid[a,b,*], Mohamed O. Abdelaziz[a,b], Mohamed E.A. Ali[b], Hosam A. Shawky[b], Erkan Oterkus[c]

[a]*Socio-economic department, Desert Research Center, Cairo, 11753, Egypt, email: Dalia_DRC@hotmail.com (D.E. Abozaid)*
[b]*Egyptian Desalination Research Center of excellence (EDRC), Desert Research Center*
[c]*Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde*

ABSTRACT

Over 2,000 km of sea coasts with different environmental conditions may provide Egypt with alternative energy solutions that may be used for electricity production and water desalination, required for the vast urban expansion, mainly along the coastal areas to relieve population pressure from the old valley and delta, and to create new community opportunities in new regions. The proposed platform discussed in this paper is a mobile platform in order to supply any costal city with fresh water to prevent any water crisis. The aim of this research paper is to make an economic comparison between floating stations and fixed stations on the ground and to determine the extent of the preference of one over the other to take the appropriate investment decision that can benefit the vast Egyptian coasts. The results of the study showed the possibility of recovering the invested capital during a period of 5 years and 5 months for the floating platform and 5 years and 8 months for the fixed ground station. Economic indicators have also been used to conduct comparison such as net present value of cash flows, cost-to-cost standard, internal rate of return, sensitivity analysis ([10% cost increase] [10% decrease in revenue] [both together]). All results were positive in favor of the floating platform of the desalination plant.

Keywords: Investment efficiency; Floating platforms; Desalination; Comparative economic study

1. Introduction

Fresh water is a finite, vulnerable and vital resource, which has social, economic and environmental implications. Today, however, the widespread scarcity, gradual destruction and increasing pollution of fresh water resources in many world regions, along with progressive encroachment of incompatible activities lead to aggravating the problem [1]. The total area of Egypt is 1,001,450 km^2, with a land area of 995,450 km^2 and a coastline of 3,500 km on the Mediterranean and the Red Sea [2]. The main source of water in Egypt is the Nile River. Egypt is unique among other countries in its dependence on water from one deterministic source. The Nile water agreement with Sudan, allocates 55.5 BCM/year to Egypt. Rainfall in Egypt occurs only in winter in the form of scattered showers. The average annual amount of effectively utilized rainfall water is estimated to be 1.3 BCM/year. This amount cannot be considered a reliable source of water due to high spatial and temporal variability. Groundwater exists in Western Desert and Sinai in aquifers that are mostly deep and non-renewable. The total groundwater volume has been estimated at about 40,000 BCM. However, current abstraction is estimated to be 2.0 BCM/year. The main obstacles in utilizing this huge resource are the great depths (up to 1,500 m in some areas) of these aquifers and deteriorating water

* Corresponding author.

quality at the increasing depths. The main water-using sector in Egypt is agriculture, followed by municipal and industrial uses [3]. In response to increasing water scarcity, over the last 30 years desalination has evolved into a viable alternative water supply. It allows us to tap non-traditional water resources with great potential to provide a sustainable, drought-proof water supply. Desalination provides only around 1 percentage of the world's drinking water, but this percentage is growing year-on-year. An expected US$10 billion investment in the next 5 years would add 5.7 million m^3/d of new production capacity. This capacity is expected to double by 2030 [4]. Globally, rapid population growth and industrial development become very hard challenges facing modern societies. Although, water covers two thirds the surface of the earth, only 3% of this water is suitable for human consumption and use [5]. By 2030, this water shortage is expected to affect up to 40% of world inhabitants [6,7]. Therefore, finding sufficient fresh water resources has become a top priority in the strategic plans of most governments [8]. Desalination has become a reliable method for water supply all over the world and had been practiced successfully for many decades and the technical and economic feasibility is obvious. The worldwide desalination capacity increased dramatically from around 35 million cubic meters daily in 2005 to about 80 million cubic meters daily in 2015, with the largest desalination plant of 1,025,000 m^3/d at Ras Al-Khair project in KSA. By 2015, there were about 17,000 desalination plants operating in 150 countries around the world [9].

According to the IDA, there are over 150 countries that use desalination to produce fresh water. In 2018, 18,426 desalination plants were reported to be in operation worldwide, producing 86.5 million m^3 of clean water each day, which is equivalent to 32 billion m^3 (BCM) annually and supplying over 300 million people. Desalinated water currently accounts for only 1 percentage of the world's drinking water [10]. However, with the rapidly falling cost of desalination coupled with increasing cost of traditional sources of fresh water and new, more stringent drinking water quality regulations, desalination is becoming more and more practical and economical [11]. Desalination plants in Arab countries have a cumulative capacity of about 24 million m^3/d. The highest desalination capacity is in the Gulf countries (81%), Algeria, (8.3%), Libya (4%) and Egypt (1.8%). Growth is expected to remain high for the next decade to meet escalating domestic water demand. Desalinated water will expand from 1.8% of the region's total water supply to an estimated 8.5% by 2025 [12].

Desalination is capital-intensive process, with costs depending on energy requirements, water production costs, technology growth trends and environmental impact. The water is subsidized, however, and sold for as little as 4 cents per cubic meter in some Arab countries. With improvements in desalination technologies, production costs are dropping. New technologies, such as reverse osmosis, electrodialysis and hybrids, are more energy efficient and better suited to different types of water [13]. These advances drove down global prices. This downward trend in the cost of desalinated water indicates that desalination technology is becoming more viable for poorer countries. Water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are currently fully exploited, while groundwater sources are being brought into full production. Egypt is facing increasing water needs, demanded by rapidly growing population, increased urbanization, higher standards of living and by an agricultural policy which emphasizes expanding production in order to feed the growing population. Currently, the Egyptian population counts about 98 million and is expected to increase to 107 million by 2025 and 151 million by 2050 [14,15]. Given that Egypt is gifted with 2,400 km of shorelines along the Mediterranean Sea and the Red Sea along with its abundant groundwater resources, seawater and groundwater desalination can be used as a sustainable water resource for domestic and industrial use in the coastal areas. Generally, the main challenge for development in such areas is the availability of the required infrastructure. Nationally, there is a vast urban expansion mainly along the coastal areas to relieve the population pressure. Considering the development at coastal areas, three alternatives for potable water supply are long distance tanker trucks, water pipelines connected to river Nile or desalination plants. Recently, PV panels have been introduced in desalination systems, but they have low efficiency and need large settlement area. Moreover, most of the Egypt's coastal areas have a shortage of land area and/or expensive for construction of PV panel systems. For this reason, renewable energy powered floating desalination plants (FDPs) are standing as an efficient solution around coastal areas.

The produced drinking water from different desalination techniques has been increasing rapidly, along the last three decades, from 500 m^3/d (1970) to 746,000 m^3/d (2020), and it is expected to be about 2.6 million m^3/d by 2037, this is because of installation of many mega capacity desalination plants at El-alamein, Gabal El-Galala and East Portsaid areas [16,17].

FDPs are relatively young technology if compared with land-based desalination solutions where a number of existing units are driven by fossil fuel and nuclear power have been established and successfully tested in commercial projects in different countries. The FDP concept generally consists of marine floating platform, desalination plant and power system. Therefore, through understanding the unique needs of Egypt, this research paper aims to develop an innovative solution to overcome the fresh water scarcity. The advantages of this technology are, first, move somewhere else when demand and country risk changed and production will be made prior to obtaining the order based on demand prediction. Second, minimize harmful effect on the environment costal area and preserve diversification of the shallow sea [18]. Hence, the aim of this research paper, in addition to limiting the health effects of the poor population around coastal areas by providing them with fresh and clean water, as well as conducting a comparative economic study between fixed and other FDPs, on coastal areas and the economic and benefit savings they achieve working to increase investments in those coastal areas

2. Data and methodology

Environment Affairs Ministry of Egypt (EAME) reports indicate that 95% of the Egyptian population is concentrated within the area between the Nile Valley and Delta which resulted in 38 million Egyptians drink from polluted waters and that led to the spread of many diseases among children such as cholera and hepatitis. The increasing population in Egypt and limited clean water resources urged Egyptian Government (EG) to initiate programs for desalination of water. Currently, reverse osmosis (RO) process is widely used to desalinate water [19,20], whereas it needs high amount of energy and it is mostly generated using fossil fuels. Recently, PV panels have been introduced in desalination systems, but they have low efficiency and need large settlement area. Moreover, most of the Egypt's coastal areas have a shortage of land area and/or expensive for construction of PV panel systems. For this reason, renewable energy powered FDPs are standing as an efficient solution around coastal areas.

In a previous work (funded by Misr El-Kheir Foundation), a mobile battery-less photovoltaic powered groundwater reverse-osmosis (MSRO) desalinating unit was designed, manufactured and field tested. Many innovative features have been incorporated in this MSRO plant prototype to maximize the energy yield. These include an integrated automatic single axis PV tracking system with programmed tilting angle adjustment as well as an autonomous cleaning system for PV modules. Excellent specific energy consumption per cubic meter of permeate was achieved leading to improved cost effectiveness of producing drinkable water in remote areas. This unit is capable of desalinating brackish and saline groundwater points with TDS up to 25,000 ppm and produces 4–5 m^3/d of drinkable water that complies with international standards. The unit was deployed in the Northwest coast of Egypt [21,22].

2.1. Technical aspects

The selection of desalting techniques depends upon many factors such as capacity, salinity, power and operational characteristics taking into consideration conditions of the site. The site selection for offshore desalination plant powered by renewable energy can be addressed using multi-criteria methodology. The methodology presented in this study is used to find the most suitable areas based on a geospatial multi-criteria analysis for wave energy converters [23,24].

In order to analyze the area of interest, the researchers were gathered data that define its characteristics as accurately as possible. These sets of data can be divided into two main categories: (1) information on the restricted areas within the region of interest, this includes all the exceptions that occur in the marine area being studied, (2) information on the relevant characteristics in the region of interest In order to ensure the sustainability of the project, the selection of site is important since it has a large portion of credits in any sustainability rating system. Therefore, it is important to avoid any site that may be an obstacle in the operation of the plant. Consequently, various criteria have been considered to be applied to select the optimum site after excluding the sites where the deployment or the operation of the plant will be impossible. In the present study case, interest region will be Egyptian coastal cities.

Each factor should be ranked and the locations which do not meet constrains should be extracted. The most important constrains are related to location restrictions such as draft or width or other industrial activities. Approximately 41 coastal cities were selected in this study (Table 1). Most of them have several different natural potentials which could make them promising location for the proposed reverse osmosis floating desalination plant (RO-FDP). In addition, these criteria cover the three sustainability spheres (environmental, economic and social).

From all the previous technical data, the researchers collected some questionnaire from the selected sites and analyzed it to design and implement the floating platform for desalination.

2.2. Socio-economic aspects

Desalinated water production, similar to many economic decisions, involves benefits and costs that are expected to occur at future time periods. The decision maker is often confronted with the problem of evaluating projects that will last several years with varying costs and benefits over the life of the project.

Some desalination techniques were studied in previous researches [25–28] from an economic point of view, and the results showed that desalination projects is still not-for-profit in Egypt where the price per m^3 of desalinated water reaches about 15 pounds/m^3.

The study is based on two sources of data, primary data generated through a sample survey covering the Red Sea governorate. The study employs surveyed data of 41 sites, in Red Sea governorate that have been randomly selected, include the input and output data. The secondary data were obtained from Holding Company for Water & Wastewater – HCWW. The data include the total quantities of water available for consumption in the Arab Republic of Egypt, and also included traditional and unconventional water sources and the inclusion of desalinated water prices in remote areas during the 2019. The method that most commonly used for addressing the present study is capital budgeting. Capital that involves large sums of money whose returns are expected to extend beyond 1 year [29]. The decision maker will search for enterprise that will produce the most net benefits. If the projects generated equal returns (annuity) throughout the project life, then the formula for determining the net present value (NPV) would be:

$$\mathrm{NPV} = S1 + S2 + S3 + \ldots \mathrm{Sn} - \mathrm{IQ}(1+\mathrm{id})(1+\mathrm{id})2(1+\mathrm{id})3(1+\mathrm{id})n \quad (1)$$

OR

$$\mathrm{NPV} = \sum n\,\mathrm{St} - \mathrm{IQ} \quad (2)$$

$$t = I \qquad (1+\mathrm{id})n \quad (3)$$

where St = the expected net cash flow (gross revenue LOE-taxes) at the end of year; IQ = the initial investment outlay at the time zero; id = the discount rate.

The net present value (NPV), referred to as the present value of cash surplus or present worth, is obtained by subtracting the present value of periodic cash outflows from the present value of periodic cash inflows [30].

Table 1
Coastal cities were selected in this study

				constraints	constraints	constraints	constraints	constraints	constraints	constraints
		Costal Cities	min water depth		shipping Routes	Military Zones	Natural Park	Cables, tunnels an	Oil and gas extract	Depth rank
Mediterranean	1	Alexandria	32 m	shallow	some restrictions	some restrictions				4
	2	Port Said	5-10m	not suitable	some restrictions	some restrictions		some restrictions	some restrictions	0
	3	Damietta	10-15m	not suitable	some restrictions				some restrictions	0
	4	Edko	5-10m	not suitable	some restrictions			some restrictions	some restrictions	0
	5	Arish	10-16m	not suitable		some restrictions			some restrictions	0
	6	Rosetta	10-15m	not suitable					some restrictions	0
	7	Ezbet Borg	5m	not suitable	some restrictions				some restrictions	0
	8	Beer Abd	10-15m	not suitable		some restrictions			some restrictions	0
	9	Rafah	10-20m	not suitable		some restrictions				0
	10	Ras ElBar	10m	not suitable					some restrictions	0
	11	New Damietta	10m	not suitable	some restrictions				some restrictions	0
	12	Sheikh Zowid	15-20m	not suitable						0
	13	Gamasa	5-10m	not suitable					some restrictions	0
	14	New BorgArab	10-15m	not suitable					some restrictions	0
	15	Baltim	5-10m	not suitable					some restrictions	0
North cost	16	Sedi Brani	25-29m	shallow						4
	17	Alamin	5-10m	not suitable						0
	18	Saloum	25-50m	shallow						4
	19	Matrouh	25-50m	shallow						4
	20	Negela								
	21	Hammam								
	22	Daba'a	25-50m	shallow		some restrictions				4
Suez Gulf	23	Suez	10-30m	shallow	some restrictions	some restrictions		some restrictions	some restrictions	2
	24	Zafarana	25-30	shallow	some restrictions				some restrictions	4
	25	Gulf of El-Zayt	25-50	shallow	some restrictions		some restrictions	some restrictions	some restrictions	4
	26	Abo Zenema	10-20 m	not suitable	some restrictions		some restrictions		some restrictions	0
	27	Ras Sedr	10-20 m	not suitable	some restrictions				some restrictions	0
	28	ElTor	20-40m	shallow	some restrictions				some restrictions	4
	29	Abu Redes	10-20 m	not suitable	some restrictions				some restrictions	0
	31	Ras Shougayr	50-60 m	shallow	some restrictions		some restrictions	some restrictions	some restrictions	4
Red Sea	32	Safaga	20-600m	deep	some restrictions		some restrictions			4
	33	Hurghada	30-640m	deep	some restrictions	some restrictions	some restrictions			4
	34	Shalaten	rfs	not suitable			some restrictions			0
	35	Berenice	50-400 m	deep			some restrictions			4
	36	Marsa Alam	50m	shallow			some restrictions			4
	37	Al Qusayr	50-1000	deep			some restrictions			4
Aqaba Gulf	38	Taba	40-100m			some restrictions	some restrictions			4
	39	Sharm Sheikh	60-1000m	deep	some restrictions		some restrictions			4
	40	Nuweiba	50-500	deep	some restrictions		some restrictions			4
	41	Dahab	50-600m	deep			some restrictions			4

Source: Questionnaire forms were collected by researchers.

The discount rate should reflect the value of the alternative use of funds. An investment project would be accepted if the NPV > 0, and rejected if NPV < 0. This is because the money being invested is greater than the present value of the net cash flow. If NPV = 0, the decision maker would be indifferent.

The internal rate of return (IRR) is reported as a percentage rather than a dollar figure such as the discounted cash flow rate of return; the definition of IRR is the interest rate received for an investment consisting of payments (negative values) and income (positive values), it occurs at regular periods [31]. The IRR may be used for ranking projects. The ranking is based on the relative size of the IRR, with the largest IRR receiving the highest rank. Acceptability of each project depends upon comparing the IRR with the investors required rate of return (RRR) sometimes called minimum acceptable rate of return (MARR). If IRR is greater than the RRR (MARR), accept the project; and reject if not.

The formula for determining the IRR would be:

$$\mathrm{IRR} = \left(\frac{\mathrm{NPVA}}{(\mathrm{NPVA} - \mathrm{NPVB})}\right)(\mathrm{IRRB} - \mathrm{IRRA}) + \mathrm{IRRA} \qquad (4)$$

where NPVA = positive net present value; NPVB = negative net present value; IRRA = interest rate associated with NPVA; IRRB = interest rate associated with NPVB.

Sensitivity analysis (SA): its ambition is to enable the reader to apply global SA to mathematical or computational model. It offers a description of a few selected techniques for sensitivity analysis, used for assessing the relative importance of model. The input factors for these techniques will answer questions such as (1) which of the uncertain input factors are more important in determining the uncertainty in the output of interest?, (2) If we could eliminate the uncertainty in one of the input factors, which should we choose to reduce most of the variance of the output? [32].

*Financial assumptions used in the analysis of the project:

The study is based on several assumptions that underlie the project›s commercial profitability analysis, as follows:

There are two desalinated water production alternatives:

- First alternative is depending on the production of desalinated water by relying on the floating platform with a capacity of 1,000 m^3/d and selling it at the tourist price of the study community.

- Second alternative is depending on desalinated water production of by relying on the fixed unit in land with a capacity of 1,000 m³/d and selling it at the tourist price of the study community.

3. Result and discussion

- The total capital costs, annual operating costs and total revenues for the two projects were estimated according to the average prices for the year 2018–2019, and they were estimated in US$ to avoid the instability of the Egyptian pound exchange rate, as they assumed their stability during the productive life estimated at 25 years.
- A 15% discount rate (which represents the calculation of the best alternative opportunity available to invest capital in society during the average years 2018–2019) was used to estimate the present value of both revenue and costs over the average useful life of the project.
- In light of the risks to which the project may be exposed, whether in the field of production or marketing, such as low productivity, high prices of production requirements, or a decrease in product prices, the study used a sensitivity analysis method to confront the risks that the project might have, as the study assumed a 10% increase in costs that it is based on the analysis, or the yield has decreased by the same percentage, and finally the possibility of both occurrences.

Table 2 data for estimating the criteria of financial analysis indicates the possibility of recovering the invested capital during a period of 5 years and 5 months for the first alternative and 5 years and 8 months for the second alternative; whereas, the net present value of cash flows (NPV) for both alternatives $3,771,868 and $3,084,397, respectively. The results also showed that the standard of return to cost (CBA) was 1.22 and 1.17, respectively. Finally, the IRR recorded ratios of 18.91% and 18.15%, which are higher than the opportunity cost available in the capital investment community represented by the current prevailing average commercial interest rate of 15%, which indicates the feasibility of expanding desalination activities.

The positive impact of the application of the floating platform technique has become clear, as the results of the four criteria for the first alternative are higher than the second, which is reflected in the order by giving priority to the implementation of the first alternative.

The data of Table 3 also indicate the estimation of the financial evaluation criteria according to the sensitivity analysis (increasing costs by 10%), (decreasing the revenue by 10%), (both together).

The results indicated in Table 3 indicate that the invested capital can be recovered during periods of 5 years and 6 months, 6 years and 2 months, 6 years and 3 months, respectively, for the first alternative, while it reached 5 years and 9 months, 6 years and 5 months, 6 years and 7 months, respectively, for the second alternative. The net present value of the cash flows 2,810.710; 1,412.472; 1,041.764 thousand $; 276.3463; 670.023 and 349.089 thousand $ for the two alternatives, respectively. Estimates of the standard return-to-cost ratio were 1.17, 1.08, 1.06, 1.15, 1.04, 1.02, and the internal rate of return recorded ratios of 18.24%, 16.66%, 16.25%, 17.87%, 15.77%, 15.44%, for the two alternatives, respectively. From the above, it is clear that by measuring the impact of potential changes in economic variables on the efficiency of investment in these projects, it still achieves satisfactory rates in relation

Table 2
Results of the financial analysis of the two projects

Standard	First alternative		Second alternative	
Payback period (P.B.P)	Year	Month	Year	Month
	5	5	5	8
Net present value (NPV)	$3,771,868		$3,084,397	
Benefit to cost ratio (CBA)	1.22		1.17	
Internal rate of return (IRR)	18.91%		18.15%	
Decision	Accept		Accept	
Arrangement	First		Second	

Source: Questionnaire forms were collected by researchers.
Field study data were analyzed using a program (cost benefit analysis).

Table 3
Sensitivity analysis for two projects

Standard	First alternative						Second alternative					
	Increasing costs by 10%		Decreasing the revenue by 10%		Both together		Increasing costs by 10%		Decreasing the revenue by 10%		Both together	
Payback period (P.B.P)	Year	Month	Year	Month	Year	Month	Year	Month	Year	Month	Year	Month
	5	6	6	2	6	3	5	9	6	5	6	7
Net present value (NPV)	$2,810,710		$1,412,472		$1,041,764		$2,763,463		$6,70,023		$3,49,089	
Benefit to cost ratio (CBA)	1.17		1.08		1.06		1.15		1.04		1.02	
Internal rate of return (IRR)	18.24%		16.66%		16.25%		17.87%		15.77%		15.44%	

Source: Questionnaire forms were collected by researchers.
Field study data were analyzed using a program (cost benefit analysis).

to the evaluation indicators used, which confirms the safety of investment in the production units under study.

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