International Journal of Environmental Studies

ISSN: 0020-7233 (Print) 1029-0400 (Online) Journal homepage: http://www.tandfonline.com/loi/genv20

Application potential of small-scale solar desalination for brackish water in the Jordan Valley, Palestine

Manal Taha & Rashed Al-Sa'ed

To cite this article: Manal Taha & Rashed Al-Sa'ed (2017): Application potential of small-scale solar desalination for brackish water in the Jordan Valley, Palestine, International Journal of Environmental Studies

To link to this article: https://doi.org/10.1080/00207233.2017.1403759

Published online: 29 Nov 2017.

INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES, 2017
https://doi.org/10.1080/00207233.2017.1403759

Application potential of small-scale solar desalination for brackish water in the Jordan Valley, Palestine

Manal Taha and Rashed Al-Sa'ed

Institute of Environmental and Water Studies, Birzeit University, Birzeit, Palestine

ABSTRACT

This paper investigates the feasibility of using solar energy coupled to reverse osmosis (RO) units for the desalination of brackish water in the Jordan Valley, the food basket for the West Bank, Palestine. Pilot-scale RO units are appropriate because of the low energy requirement, market availability, size and area and convenience of installation in the Jordan Valley's harsh conditions. The study concerned the Marj Naajeh desalination unit. The economic feasibility was compared to other alternative energy sources (diesel generators and network electricity). The environmental costs were considered as well as the economic costs. The results obtained suggest upgrading 162 agricultural wells of different water capacities and quality. Further studies on design capacity and efficiency of future desalination facilities would be beneficial.

KEYWORDS

Brackish water; desalination; RO; solar PV

Introduction

Palestinians in the West Bank and the Gaza Strip are suffering from water shortage because of Israeli restrictions on access to and use of the available water resources, and consequent over-exploitation of current accessible resources. Water demand increases; supply appears to be limited. This is a direct result of the Israeli Occupation, which obstructs the implementation of the water provisions under the Oslo Accords.

The Jordan Valley is the most affected area as Israel controls 80% of the district [1]. The Israeli Occupation restricts the activities of Palestinians to their land, and includes demolitions of Palestinian houses, water cisterns and wells, closure of roads and blockages. Many Palestinian Bedouin communities are forcibly evicted from their land. The human and economic costs to the Palestinians are severe, but they continue to try to use the available water resources to maintain a tolerable living standard. One is the efficient use of brackish water wells, where use is limited by the volume and quality [2].

This research study aims to assess the feasibility of using brackish water wells in the Jordan Valley including the socio-economic impacts on the citizens. Other studies have reported the urgent need to introduce a reform policy for the agricultural sector in the Jordan Valley, the food basket of the West Bank, Palestine [2,3].

CONTACT Rashed Al-Sa'ed rsaed@birzeit.edu

This paper highlights the applicability of alternative solutions to overcome the water and energy issues through renewable energy desalination to ensure water security in the Jordan Valley. The objective is to investigate the application potential of brackish water desalination in the Jordan Valley using solar energy, a renewable source, to produce irrigation water suitable for agricultural purposes.

Materials and methods

The researchers collected and analysed data. This approach comprised baseline data assessment of the Jordan Valley concerning water, energy, and socio-economic features. Data were collected from the Palestinian Water Authority (PWA), the Palestinian Central Bureau of Statistics (PCBS), and from local non-governmental organisations as well as face-to-face communication with selected farmers. The PWA's water data were processed and categorized using Excel software package, and then inserted into GIS software to produce a new map depicting the distribution of agricultural wells along the Jordan Valley.

The research methodology was to assess relevant book chapters, project reports of international organizations and scholarly articles in a technology assessment frame of reference. We paid particular attention to those desalination technologies used for brackish water treatment in arid and remote areas; above all, to desalination technologies using solar energy.

The local experience regarding the brackish water desalination in the Jordan Valley was assessed and presented. An economic analysis of desalination costs was performed. A comparative analysis was then made on desalination technologies using other energy sources: electricity network; diesel generator; and off-grid solar Photovoltaic (PV). An existing pilot-scale desalination unit, installed in Marj Naajeh, was used as a case to validate the feasibility of a wide-scale scheme for harnessing renewable energy in the Jordan Valley.

The economic analysis included estimation of the total capital expenditures according to the following equation reported by Hillier et al. [4]:

$$\text{Total Cost} = \text{Investment Cost} + \text{O\&M Cost} + \text{Environment Cost} \tag{1}$$

where,

- Investment cost inclusive of desalination and Photovoltaic system cost referred to living examples from Marj Naajeh and recent reports.
- Operational and maintenance costs include labour, operational material, testing, and replacement of filters, inverters, and batteries.
- Environment cost was estimated based on IEA [5] and TU Delft estimations for each type of energy source [6].
- Cost of oil in second quarter of 2016 is US$1.5 /L [7].

The specific costs of produced water were calculated using Equation 2 as suggested by Hillier et al. [4]:

$$\text{The Average produced water Cost}\left(\frac{\text{USD}}{\text{m}^3}\right) = \frac{\text{Total Cost }\left(\frac{\text{USD}}{\text{year}}\right)}{\text{Total Produced WAter }\left(\frac{\text{m}^3}{\text{year}}\right)} \tag{2}$$

Current situation of the Jordan Valley

The ground water aquifer system in the West Bank should provide 118 million cu m per year (MCM/y). Under the Oslo Accords, the water abstraction share of the Palestinians is 54 MCM/y in addition to 78 MCM/y for future needs from the eastern aquifer [1]. According to the PWA report [8], less than 98 MCM of the stated potential has been withdrawn in 2010 from all aquifers.

The Jordan Valley lies along the eastern side of West Bank, and extends from Bissan, in the north, to Hebron district, in the south. The Jordan Valley includes 65 communities, of which Israel acknowledges only 14 towns, and villages including 50 Bedouin communities [9]. According to PCBS [10], about 49,390 inhabitants are living in the Jordan Valley.

The total area of the Jordan Valley is 161,172 ha of which 10,765 ha are agricultural [3]; but there is only limited access to 6000 ha of the agricultural land because of the Israeli military restrictions [2]. The small volume and low water quality of brackish water wells are a further challenge to the agricultural sector in regard to efforts at sustainability in the area [2].

The Jordan valley, an arid region, has a hot summer (22.4–37.6 °C) and warm winter with variable temperatures (7.4–19.3 °C). The annual rainfall is below 200 mm, distributed only over 20–25 rainy days [11].

The communal services provided to Bedouin communities in the Jordan Valley are limited to basic health and educational services. Most of the area's communities are remote from the electricity supply system; it would be very costly to connect these communities [12]. Hence, citizens depend on diesel generators [13] to obtain electrical power, and pay US$1.8 /L for diesel [14].

There is significant potential for Solar PV in Palestine. According to the Energy Research Centre of An-Najah University [12], sunshine hours in Palestine exceed 3000 h p.a. with an average production potential of 5.4 KW per square metre. Based on the Palestinian Renewable Energy strategy [14], the government provides exemption from 'added value' (benefit) taxation on the PV equipment [15] during the implementation phase.

Drinking water service is available only in 15 communities. The water supply derives from the supply network of Jericho city, or water is purchased from Mekorot, an Israeli Water Company [9]. On the other hand, the residents of Bedouin communities depend on their water supply through water tankers, the Israeli Water Company filling points, and nearby freshwater springs. The location of these interim water sources exerts additional costs for water transport [8]. Therefore, the costs for one cubic metre (m^3) of water can vary between US$4.28 and US$11.43, varying with the transport distance to individual communities from the water wells or the water filling points [8].

For agricultural uses, the citizens of the Jordan Valley depend on PWA licensed agricultural wells. Figure 1 illustrates the location of the 162 agricultural wells in the Jordan Valley. The total annual capacity can reach 16.63 MCM; the summation of the yearly abstraction rate is set for only 121 agricultural wells [16].

Table 1 summarises the capacity categorization (m^3/h) of the agricultural wells, assuming a daily operation for the water well for 18 h.

The water volume derived from the wells is limited through annual rainfall decline [3], and because of the Israeli restrictions on the rehabilitation of the water wells [9]. Agricultural networks, linked to agricultural wells, transport water to surrounding agricultural lands [9].

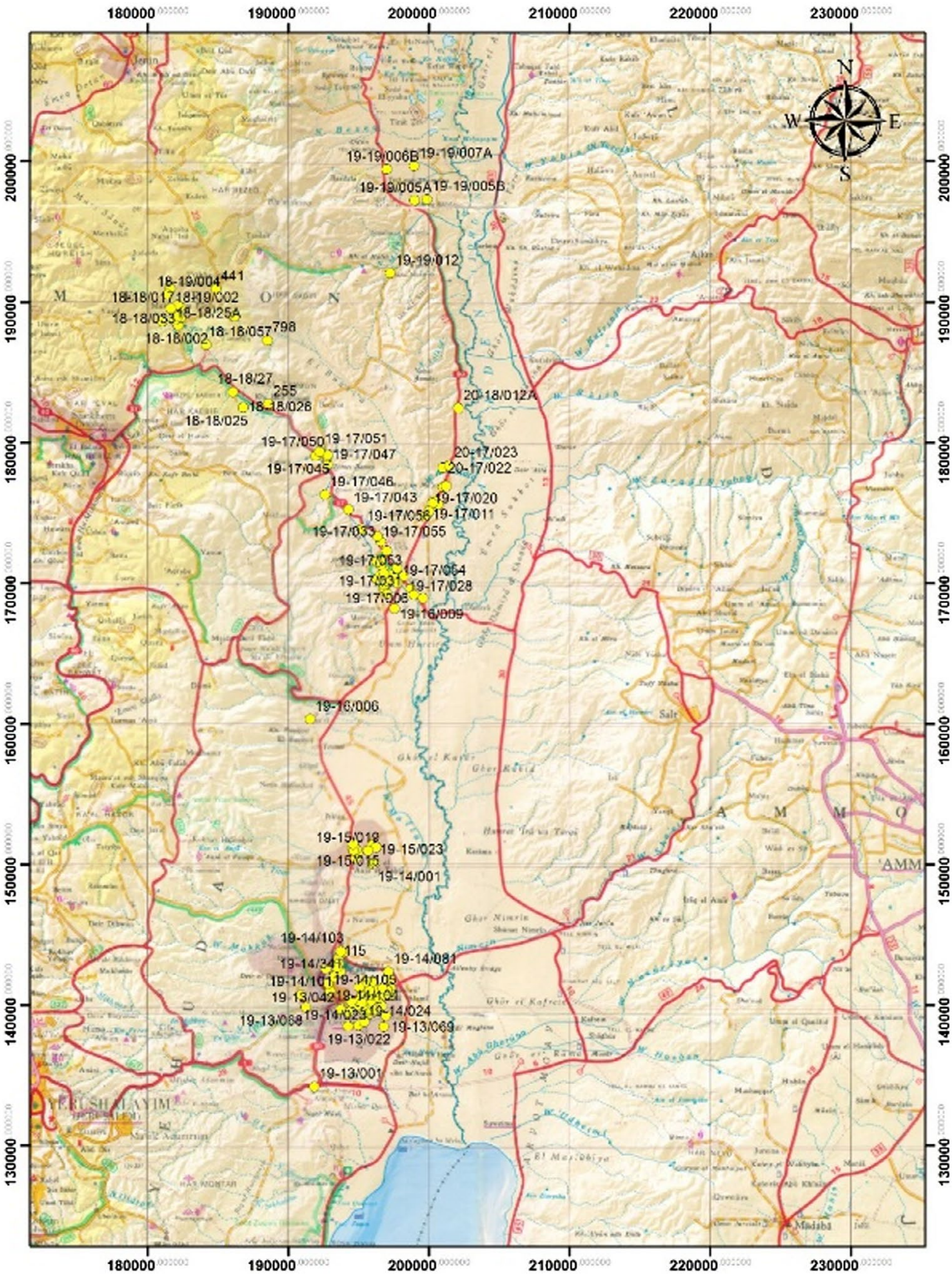

Figure 1. Agricultural wells distribution in the Jordan Valley [16]. Source: Palestinian Water Authority [PWA].

The PWA monitors the water quality for Jordan Valley wells. The water monitoring data revealed that most of the agricultural wells yield brackish water. This has a wide range of salinity content, measured as electronic conductivity (EC). The EC value of brackish water wells ranges between 360 µs/cm and 6390 µs/cm [17]. The water quality deteriorates when

Table 1. Agricultural wells categorization [16].

Categorization licensed abstraction (m^3/h)	No of wells
Less than 10	42
(10–20)	32
(20–30)	24
(30–40)	9
(40–50)	5
(50–60)	3
(60–70)	2
(more than 70)	4

heading to the east and north east of Jericho and Tubas districts, and is affected by the salinity of the Jordan Valley aquifer [18].

Results and discussion

Available desalination technologies and renewable energy combinations

The availability of both brackish water and renewable energy sources, and the urgent need to treat and reuse brackish water call for appropriate and efficient technological solutions. Achieving this aim will ensure the security of relations among water, energy, land, and food in the study area.

A few studies have reported that small desalination units are adequate for remote arid areas, combining desalination and solar energy options [19]. The desalination technologies used varied with the specific site conditions.

Several technologies are adapted on a market scale as Multi Stage Flash, Multi effect Boiling, Reverse Osmosis (RO), Electrodialysis (ED), Electrodialysis Reverse (EDR), and Solar Stills (SS). Other technologies tested include Membrane Distillation (MD), Humidification and Dehumidification [20]. Depending on the water treatment process of desalination units, the solar energy can be applied as thermal energy to drive the phase change processes, or as electricity to drive the membrane processes [20].

Brackish water desalination is an energy consuming process, and the energy requirement depends on the technology installed and the quality of water source [20]. For this purpose, both conventional and unconventional energy sources can be used. Fossil fuels are no longer desirable options for large-scale desalination units, because of the shortage of and increased cost of fuel, unreliable electricity networks, and the greenhouse gas emissions [19]. In the Middle East particularly, solar energy is a sustainable alternative [19]. There is now increasing interest in the application of solar-driven desalination units in remote rural areas, lacking electrical networks [20].

Solar Stills, Solar Photovoltaic and RO (RO-PV) [19] or ED (ED-PV) [21], offer a promising combination of renewable energy and brackish water treatment [20]. Likewise, MD proved a technically feasible alternative when combined with solar energy [22]. Because of the high capital and annual running costs of thermal desalination technologies, they are not recommended for brackish water treatment at large scale [19].

The technology selection of the desalination process depends on site-specific conditions [23], climate conditions, technical aspects, the existing system conditions, energy availability, water quality, capital and operation expenditures (O&M) [24].

Shatat et al. [24] reported desalination costs and showed variable expenditures influenced by the water quality, capacity, energy cost, and post treatment requirements [24]. These researchers found that the produced water cost is inversely proportional to the desalination capacity.

Various researchers [25–30] have reported on three main desalination technologies, which are described briefly as follows:

- *Solar Stills* use the greenhouse effect to distil water. The process consists of a greenhouse with a pond, and a storage tank. It is a simple and energy free process. Upgrading the system in different shapes aims at increasing the daily efficiency from 3–4 to 5–6 L/m^2. System upgrading is made possible by adding a Single Effect Process and using heat pipe collectors [25]. Kalogirou [26] reports that solar stills are feasible to desalinate up to 200 m^3/day of brackish water. Other studies [27,28], report on operational costs for the produced water (US$12/m^3) from brackish water.
- *Electrodialysis (ED)* is an electrochemical process of membrane technology aimed to reduce salt concentrations. ED depends on transferring ions from the feed water compartment, through membranes, under the influence of an electrical potential difference, mainly a direct electric current (DC) to remove salt ions in the brackish water [20]. EDR is an upgraded process entailing a continuous operation with a polarity change of the electrodes every 15 or 20 min [29]. DC is required to operate the ED the system, hence it can be coupled with a PV unit without an energy inverter [30]. The energy consumption is proportional to salinity grade [29], and is highly sensitive to the water quality, affecting the required DC capacity. The operation of hybrid ED-PV system is a clean and economic desalination option for remote rural areas. The specific energy consumption for ED-PW system is one kWh/m^3 [29]. The hybrid ED-PV desalination is still a complex system; there are energy losses relating to the alteration of charge direction under maximum power [29].
- *Reverse Osmosis (RO),* an advanced technology, applies semi-permeable membranes to separate water from salt solutions (brackish and marine water) under pressure. The quality of the produced water is pressure dependent [20]. Hence, RO is an energy demanding process. The efficiency of RO has improved through new development of low cost membranes, use of energy recovery devices, use of enhanced membranes, and staging [31]. RO is currently considered best cost competitive if combined with solar energy [12,19]. For example, Jordan has invested in small-scale RO plants to desalinate brackish water, and has reached a capacity of 230,000 m^3/day in 2008 [32]. In Palestine, there are only four (4) small-scale desalination units (solar-driven), installed in the West Bank [33]. Gaza Strip has 29 small-scale desalination systems [34]; some are solar-driven systems.

The energy requirements and the costs of produced water by RO are variable. The energy consumption of RO installed for brackish water desalination can range between 0.5 and 2.5 kWh/m^3 [32]. Others [31] have reported 2–3 kWh/m^3 [31] yielding a water cost of US$0.2-0.7 /m^3 [31]. The costs of water desalination follow the trade-off scale considering the plant capacity [19]. Plant Capacities of variable range (20-1200 m^3/day) can offer a wide range of water costs (US$0.78-1.33 /m^3). A plant capacity of less than 20 m^3/day has a cost range of US$5.63-12.90 /m^3. Furthermore, the cost of produced water from brackish water using PV has ranged between US$5.85-13.42 /m^3 [19]. Bashart [35] estimated the operational cost for the solar-driven RO in Marj Naajeh, desalinating brackish groundwater, at US$0.15 /$m^3$. The capital cost of the unit was US$160,000. The specific energy costs are based on 1.125 kWh/m^3.

Shatat et al. [24] compared the percentage of the annual capital and energy costs for conventional and renewable energy resources of desalination systems. They found, the capital costs of a conventional desalination system were 22 to 27% higher and associated with higher energy cost (59–63%) compared with solar-driven desalination facilities [24].

Application potential of desalination and renewable energy in Palestine

The economic cost of desalination technology is crucial. It covers the annual capital and operational expenditures (e.g. personnel, maintenance, energy, transportation, and environmental aspects) [32]. For Solar Stills, it is obvious that the land requirement is the main constraint, and forms a political challenge in the Jordan Valley. Forty-two agricultural wells with capacities less than 10 m^3/h require 4.3 ha, (land required to produce 1-metre cube is estimated at 6857 m^2). Loss of fertile agricultural land in order to construct the solar stills is not feasible. Despite low energy requirements for the ED, it is not commonly used on a wide scale in water desalination in countries adjacent to Palestine owing to complexity and energy sensitivity to salinity [29].

Several studies [19,29] have reported recommendations on the selection of RO-PV combination, which proved to be successful in raising the treatment efficacy and reducing the specific energy requirements. Additionally, the market availability of RO-PV in Palestine, Israel, and Jordan, can increase the widespread use of RO-PV applications. Unfortunately, the unstable political environment is a problem for the application potential in Palestine. The Israeli authorities deny construction permits for the Palestinians living in Area C of the Jordan Valley. Marj Naajeh project is an example; only the foundation and steel covering were constructed [35].

Acknowledging the high capital expenditures for PV driven desalination systems, an economic analysis of diesel and renewable energy driven systems was performed. This can provide decision makers with data on the economic feasibility of such projects in the Jordan Valley.

Accordingly, this study used the economic cost of upgrading RO with electricity into RO–PV for an existing project in Marj Naajeh [35] as a case study. It is the only desalination facility for research purposes and has reliable data available. The comparison also includes a proposal to replace RO- Diesel with an RO-PV system. The capital cost of the desalination unit US$160,000 includes the desalination unit (2 stacks), storage of brackish water with capacity 150 m^3, storage of treated water with capacity 250 m^3, two pumps (75HP), and brine disposal pipe of length 2.5 km [35]. Table 2 summarises the main technical and design specifications for the solar-driven desalination system in Marj Naajeh.

While using desalinated water, no costs benefits were assumed for an increased agricultural production. But, the gain in reduced environmental costs through CO_2 emission reductions is included in the costs based on the energy source used.

Table 2. Technical design data for the RO-PV system and quality of the raw water source (brackish water well) in Marj Naajeh and Ministry of Agriculture, Ramallah, Palestine [35].

Parameter	Raw water source quality	RO-PV data
Pumping Capacity (m^3/h)	120	
Pumping Head (m)	120	
Operating Hours per day	18	
Operating Months per year	10	
Electric Conductivity (µs/cm)	6300	
Desalination Capacity (m^3/h)		75
Treatment Efficiency (%)		73
Produced Water (m^3/h)		55
Energy Requirement for RO (kWh/m^3)		1.125
Diesel Generator Cost (USD)		10,000

The following main assumptions were made:

- Land Cost is not included assuming farmers are the project owners,
- Cost of PV include (PV, inverters, DC charge controller, batteries for 1 day storage) is US$4250 in 2013 [36] and US$2,000 in 2016 (personal communications),[1]
- 1 kWh PV requires 10 m^2 [12],
- Cost of Diesel generator is added to the desalination unit investment cost,

Table 3 summarizes estimates of capital expenditure for each option, the expected operational expenditures (O & M) including inverter replacement after 10 years and batteries replacement after 7 years [36]. The environment cost was calculated considering that diesel generator and electricity network produce 778, and 698 g/kW of CO_2 respectively [5]. The cost of the emissions is US$0.18 /kg [6].

There has been a projection of cash flow of costs to make an economic analysis and comparison. Table 4 lists the estimated average produced water cost for the three energy resources. The cost of the system is consistent to assess the energy cost component [19], where the capital cost of energy in this study was set at 84%. On the other hand, the produced water cost is lower than those given by other studies [19,24,31,32]. The reason is the lower energy required by the RO-PV system in the Marj Naajeh example (1.125 kWh/m^3) compared to other reported systems [19,31,32] and other factors are the well water capacity, the salinity and the water treatment efficacy [24].

The study analysed the current water and energy challenges in the Jordan Valley, and presented sustainable technologies for brackish water desalination using solar energy.

Table 3. Cost estimate of different energy sources.

Emery source	Diesel (2013)	Diesel (2016)	Electricity network	Solar PV (2013)	Solar PV (2016)
Total Investment Cost (USD)	170,000	170,000	160,000	971,446	541,857
Total Operation and Maintenance Cost (USD/Year)	59,038	49,582	6083	5700	4000
Environment Cost (USD/Year)	35,093	35,093	31,079	–	–
Project Life (Year)	20	20	20	20	20
Average Cost (USD/Year)	102,631	93,175	49,176	54,272	31,093
Total Water Production (m^3/Year)	297,000	297,000	297,000	297,000	297,000

Table 4. Calculated costs for desalinated water using different energy sources.

Energy source (US$/$m^3$)	Diesel (2013)	Diesel (2016)	Electricity network	Solar PV (2013)	Solar PV (2016)
Average Cost of produced Water	0.346	0.314	0.166	0.183	0.105
Average Cost of produced Water exc. Environment Cost	0.227	0.196	0.047	0.183	0.105

The results of this study suggest that RO-PV is a feasible option, confirming the views of previous published studies. The economic comparison of energy cost underlines the feasibility of coupling RO to the off-grid Solar PV. On the basis of the Marj Naajeh desalination unit, the average desalination cost for the produced water is calculated at US$0.183/$m^3$ compared to US$0.346 /$m^3$, if diesel is used as the energy source in year 2013. The same cost pattern was obtained for the year 2016, where the produced water costs can reach US$ 0.314 /m^3 compared to US$ 0.105 /m^3. Fluctuating diesel prices might affect the water cost, in contrast with the consistent price drop in solar PV systems. Apart from environmental costs, the average cost of desalinated water produced by the PV are still competitive to those costs for diesel driven RO systems, and have a payback period of 4.6 years using 2016 figures. It is notable that the desalination alternatives in this study revealed lower production costs compared to fresh water supplies (drinking water) provided to households or the transport of irrigation water to agricultural land (US$ 4.28-11.43 /m^3).

Desalination units, driven by electricity network, can produce water at feasible production cost; but where such networks do not exist, the construction costs of the electricity networks should be included in the overall capital expenditure. The results of this study indicated that RO-PV has a higher capital expenditure but a lower annual operational expenditure. This is a solid finding, which water decision makers can use in planning a sustainable use of scarce resources.

Conclusions

The results obtained in this study favour the usage of reverse osmosis (RO) technology coupled with solar Photovoltaic (PV) units as an economically feasible alternative for brackish water desalination. These RO-PV systems overcome the current water and energy crises in the Jordan Valley. The energy requirements and produced water costs are linked to the capacity and raw water quality. The results of this study suggest that there should be the application of RO-PV for the desalination of 162 agricultural wells in the Jordan valley. Obtained economic data showed that RO-PV system is an economical feasible desalination alternative. This option will secure adequate irrigation water and ensure agricultural land availability, preventing its abandonment. Finally, more detailed assessment studies on the environmental and social impacts would be beneficial.

Note

1. Personal communications between M. Taha and representatives of five Palestinian Solar PV companies have produced figures for costs.

Acknowledgement

The financial support provided by the European Desalination Society Secretariat, Italy and the Higher Council for Innovation and Excellence, Palestine, is highly appreciated.

Disclosure statement

Authors declare no potential conflict of interest.

Funding

This work was supported by the by the European Desalination Society Secretariat, Italy and the Higher Council for Innovation and Excellence, Palestine.

ORCID

Rashed Al-Sa'ed http://orcid.org/0000-0002-9245-7870

References

[1] Israel Ministry of Foreign Affairs, 1995, The Israeli-Palestinian interim agreement (Annex III). Geneva: Oslo Accord. Available online at: http://mfa.gov.il/MFA/ForeignPolicy/Peace/Guide/Pages/default.aspx (accessed 20 August 2017).

[2] Maan, 2012, Spotlight 10: The status of Palestinian agriculture in the Jordan Valley. Available online at: http://www.maan-ctr.org/old/pdfs/FSReport/spotlight/Spotlight10.pdf (accessed 29 November 2016).

[3] Abu Kubi, M., 2003, *Detection and mapping of the land use/land cover changes in the "Jordan Valley" using Landsat imageries*. Available online at: http://www.arij.org/publications(4)/Papers/2003/2003%20Detection%20and%20mapping%20of%20the%20land%20use%20changes%20in%20the%20jordan%20valley.pdf (accessed 29 November 2016).

[4] Hillier, D.J., Ross, S.A., Westerfield, R.W., Jaffe, J. and Jordan, B.D., 2010, *Corporate Finance*, (1st European Ed.) (Maidenhead: McGraw-Hill Education).

[5] IEA, International Energy Agency, 2016, CO_2 Emissions from fuel combustion: highlights, 2016 Edition. Available online at: https://www.iea.org/publications/freepublications/publication/ (accessed 16 August 2017).

[6] TU Delft, 2012, The model of the eco-costs/value ratio (EVR). Available online at: http://www.ecocostsvalue.com/EVR/model/theory/subject/2-eco-costs.html (accessed 12 January 2016).

[7] Global Petrol Prices, 2016, Global petrol prices: diesel prices. Available online at: http://www.globalpetrolprices.com/diesel_prices/#hl125 (accessed 16 January 2016).

[8] PWA, Palestinian Water Authority, 2012, *Annual Status Report on Water Resources in the Occupied State of Palestine* 2011, Available online at: http://pwa.ps/page.aspx?id=0PHprpa2520241944a0PHprp (accessed 29 August 2016).

[9] UNICEF and GVC, 2010, Assessment of Water availability and access in the areas vulnerable to drought in the Jordan Valley. Available online at: http://ecopeaceme.org/uploads/UNICEF_Water_2010.pdf (accessed 12 August 2016).

[10] PCBS, Palestinian Central Bureau of Statistics, 2013, Localities in Jericho & Al Aghwar Governorate by type of locality and population estimates 2007–2016. Available online at: http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/jerich.htm (accessed 16 June 2016).

[11] ARIJ, Applied Research Institute Jerusalem, 1995, Applied Research Institute Jerusalem, 1995, Environmental Profiles for the West Bank, Volume 2: Jericho District. Available online at http://www.arij.org/files/admin/1995-2_Environmental_Profiles_for_the_West_Bank_Volume_2_Jericho_District.pdf (accessed on 11 July 2017).

[12] Ibrik, I., 2008, *The Use of Renewable Energies (Solar Energy) in the Desalination of Brackish Water in the Lower Area of Wadi Al-Faraa (Al-Jiftlik)*. (Nablus, Palestine: Energy Research Center, An-Najah University).
[13] Maan, 2010, To exist is to resist: save the Jordan Valley. Available online at: http://jordanvalleysolidarity.org/reports/to-exist-is-to-resist-save-the-jordan-valley/ (accessed 29 November 2016).
[14] ENPI, European Neighbourhood Instrument, 2012, Paving the Way for the Mediterranean Solar Plan, Power System 2020. (Palestine). ENPI 2010/248-486. Available online at: http://www.enpi-info.eu/library/content/paving-way-mediterranean-solar-plan%E2%80%93-power-system-2020-palestine (accessed 11 September 2017).
[15] RCREEE, Regional Center for Renewable Energy and Energy Efficiency, 2013, *Arab Future Energy Index™ (AFEX) Renewable Energy, Index Report*. Available online at: http://www.rcreee.org/sites/default/files/reportsstudies_afex_re_report_2012_en.pdf (accessed 12 September 2017).
[16] PWA, Palestinian Water Authority, 2011, *Water Wells in Jericho and Tubas 2011*.(Ramallah, Palestine). http://pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/Annual%20Water%20Status%20report%202011.pdf (accessed 16 August 2017).
[17] PWA, Palestinian Water Authority, 2011, *Water Quality data for Jericho & Tubas 2011*. (Ramallah, Palestine). http://pwa.ps/userfiles/file/%D8%AA%D9%82%D8%A7%D8%B1%D9%8A%D8%B1/Annual%20Water%20Status%20report%202011.pdf (accessed 16 August 2017).
[18] Marie, A. and Vengosh, A., 2001, Sources of salinity in ground water from Jericho area, Jordan valley. *Ground Water*, **39**, 240–248.
[19] Shatat, M., Worall, M. and Riffat, S., 2013, Opportunities for solar water desalination worldwide: Review. *Sustainable Cities and Society*, **9**, 67–80.
[20] Kalogirou, S.A., 2009, Solar desalination systems. In: S.A. Kalogirou (Ed.) *Solar Energy Engineering*. (Boston, MA: Academic Press), pp. 421–468.
[21] Ortiz, J.M., Expósito, E., Gallud, F., García-García, V., Montiel, V. and Aldaz, A., 2008, Desalination of underground brackish waters using an electrodialysis system powered directly by photovoltaic energy. *Solar Energy Materials and Solar Cells*, **92**, 1677–1688.
[22] Qtaishat, M.R. and Banat, F., 2013, Desalination by solar powered membrane distillation systems. *New Directions in Desalination*, **308**, 186–197.
[23] Younos, T., 2005, The Economics of Desalination. *Journal of Contemporary Water Research and Education*, **132**, 39–45.
[24] Shatat, M., Worall, M. and Riffat, S., 2013, Economic study for an affordable small scale solar water desalination system in remote and semi-arid region. *Renewable and Sustainable Energy Reviews*, **25**, 543–551.
[25] Chaibi, M.T., 2013, Thermal solar desalination technologies for small-scale irrigation. *American Journal of Energy Research*, **1**, 25–32.
[26] Mahmoud, M.M. and Ibrik, I.H., 2006, Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid. *Renewable and Sustainable Energy Reviews*, **10**, 128–138.
[27] Khayet, M., 2013, Solar desalination by membrane distillation: Dispersion in energy consumption analysis and water production costs (a review). *New Directions in Desalination*, **308**, 89–101.
[28] Xiao, G., Wang, X., Ni, M., Wang, F., Zhu, W., Luo, Z. and Cen, K., 2013, A review on solar stills for brine desalination. *Applied Energy*, **103**, 642–652.
[29] Uche, J., Círez, F., Bayod, A.A. and Martínez, A., 2013, On-grid and off-grid batch-ED (electrodialysis) process: Simulation and experimental tests. *Energy*, **57**, 44–54.
[30] Ortiz, J.M., Expósito, E., Gallud, F., García-García, V., Montiel, V. and Aldaz, A., 2007, Electrodialysis of brackish water powered by photovoltaic energy without batteries: direct connection behaviour. *Desalination*, **208**, 89–100.
[31] WIPO, World Intellectual Property Organization, 2011, Patent Landscape Report on Desalination Technologies and the Use of Alternative Energies for Desalination. Patent Landscape Report on Desalination Technologies and the Use of Alternative Energies for Desalination. Available

online at: http://www.wipo.int/export/sites/www/patentscope/en/programs/patent_landscapes/documents/patent_landscapes/948-2E-WEB.pdf (accessed 12 July 2017).

[32] UN, United Nations, 2009, *ESCWA Water Development Report 3: Role of Desalination in Addressing Water Scarcity*. Available online at: http://large.stanford.edu/courses/2013/ph240/rajavi2/docs/sdpd-09-4.pdf (accessed 12 October 2017).

[33] Bsharat, J., 2013, *Feasibility of Membrane Based Treatment Technology for Desalination of Brackish Water and Effluent Reuse*. M.Sc Thesis, (Birzeit, Palestine: Birzeit University).

[34] Abu Mayala, Y., Abu Amr, S. and Shatat, O., 2009, Evaluation of common and small-scale brackish water desalination plant for drinking purposes in Gaza Strip. Presented at the International Conference on the Palestinian Environment, Nablus, Palestine, 6 October.

[35] MoA, Ministry of Agriculture, 2013, *Marj Naajeh Desalination Unit for Agricultural Uses*. (Ramallah, Palestine: Ministry of Agriculture).

[36] Hodali, R., 2013, *Feasibility Study for Solar Photovoltaic Pilot Projects: Renewable Energy – Solar Photovoltaic Pilot Project*. (Palestine: Ramallah).