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Rola Quba'a, Mutasem El-Fadel, Majdi Abou Najm & Ibrahim Alameddine

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RESEARCH PAPER

Comparative assessment of joint water development initiatives in the Jordan River Basin

Rola Quba'a, Mutasem El-Fadel, Majdi Abou Najm and Ibrahim Alameddine

Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon

ABSTRACT

This paper presents a comparative assessment of developmental initiatives to increase regional water supply in the Jordan River Basin using a Multi Criteria Decision Analysis technique with sensitivity analysis on criteria weights. The results indicate that the Red Sea–Dead Sea Conveyance (RSDSC) constitutes an optimal option within the context of alleviating water shortage and promoting regional cooperation. While a surface water pipeline from Turkey emerges as an attractive option when the quantity of delivered water is emphasized, the potential for out of basin water transfers are becoming increasingly less desirable with population growth, political turmoil in the region, development, and climate change challenges.

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Jordan River Basin; Red Sea–Dead Sea Conveyance; Seawater Desalination; Transboundary water; Multiple Criteria Decision Analysis; Simple Additive Weighting

1. Introduction

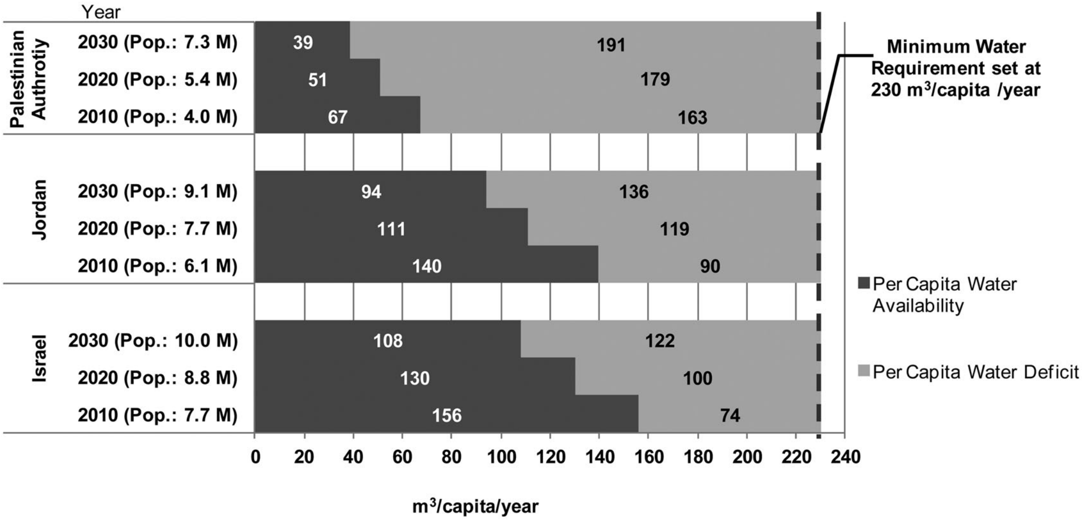
Conflicts over shared water resources in the Jordan River Basin (JRB) are associated with scarcity of resources amongst riparian countries[1]. While achieving a consensus allocation strategy coupled with effective management of the basin's water may decrease water shortages (King and Jaafar 2015), the need to augment water supplies remains a priority particularly for the lower JRB, where the Palestinian Authority (PA) experiences the lowest per capita annual water withdrawal of around 80 m^3/capita/year followed by Jordan and Israel at around 190 and 290 m^3/capita/year, respectively, with all three being well below the 'absolute scarcity' benchmark of 500 m^3/capita/year (FAO 2016). Water scarcity in the basin is expected to worsen with the increase in water demand brought about by continued population and economic growth, accompanied by urbanization, and exacerbated by potential climate change impacts (El-Fadel 2010, Becker *et al.* 2012, Gunkel and Lange 2012, Comair *et al.* 2013, Chen *et al.* 2015). The basin is experiencing a drop in precipitation, which is partially attributed to increased concentrations of aerosols (Givati and Rosenfeld 2004, 2007). Moreover, global circulation simulations are projecting that the basin will experience an increase in temperature and a decrease in precipitation and consequently an increase in water demand (Hoff *et al.* 2011). This harsh hydrological setting is further complicated by the deep-rooted Arab-Israeli political conflict involving territorial disputes and issues of national identity and security (Libiszewski 1997, Medzini and Wolf 2004).

At present, the three most stressed riparians (Israel, Jordan, and PA) derive an appreciable amount of their renewable freshwater from the JRB and the groundwater of the Mountain Aquifer (between Israel and PA). A simple preliminary assessment of available freshwater resources for the three riparians reveals that existing resources are insufficient to meet current and future needs of the region, irrespective of allocation.

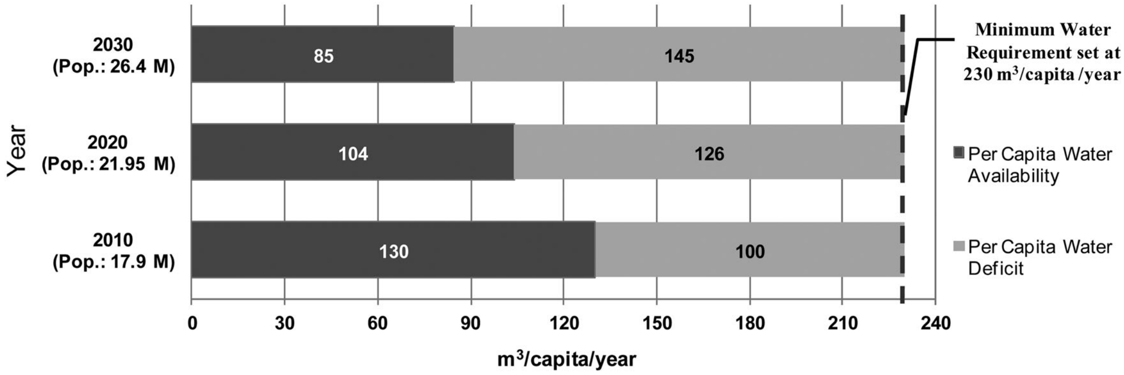
Taking the Israeli 2050 per capita water allocation rate of 230 m^3/capita/year (Israel Water Authority 2012) as a benchmark for the entire basin, a general water balance was calculated to compare water demands to the natural renewable freshwater water supply (i.e. excluding any non-conventional water resources such as desalination or wastewater reuse) in those countries using two scenarios: (a) holding the consumption rates across countries steady over time and dividing the national available natural renewable freshwater resources for each country by its total population, and (b) assuming an equal distribution of the total available natural renewable freshwater resources over the total sum of their populations. The Israeli and Jordanian populations were based upon projections reported by Israel Statistical Abstract (ICBS 2011) and the Jordan's Department of Statistics population projection for the time period 2010–2030 (DOS 2014), respectively. The population within the PA was based on the Palestinian Central Bureau of Statistics estimates (PCBS 2016) with a 2.8% linear population growth rate. The results (Figure 1) show that irrespective of water allocation scenario between riparians and despite using the rate of 230 m^3/capita/year which is well below 'the absolute water scarcity' benchmark of 500 m^3/capita/year, all countries will experience an ever increasing deficit over time (Figure 1).

The projected water deficits establish a need for securing additional supplies to alleviate water scarcity. As such, a growing programme of desalination plants has been initiated in Israel along the Mediterranean Coast, with the aim to supply nearly 23% of the country's projected 2050 water needs; but for Jordanians and Palestinians, the situation remains bleak. Jordan is heavily dependent on external water resources, which account for 27.2% of its total renewable water resources (FAO 2016); and it will probably remain so in the future (Schyns *et al.* 2015). The Jordanians are already overexploiting existing non-renewable groundwater resources (the Disi aquifer) and have limited sea access for desalination along the

CONTACT Mutasem El-Fadel mfadel@aub.edu.lb



(a)



(b)

Figure 1. Average per capita water deficit in Israel, Jordan, and the PA based on available natural freshwater resources and excluding non-conventional water resources.

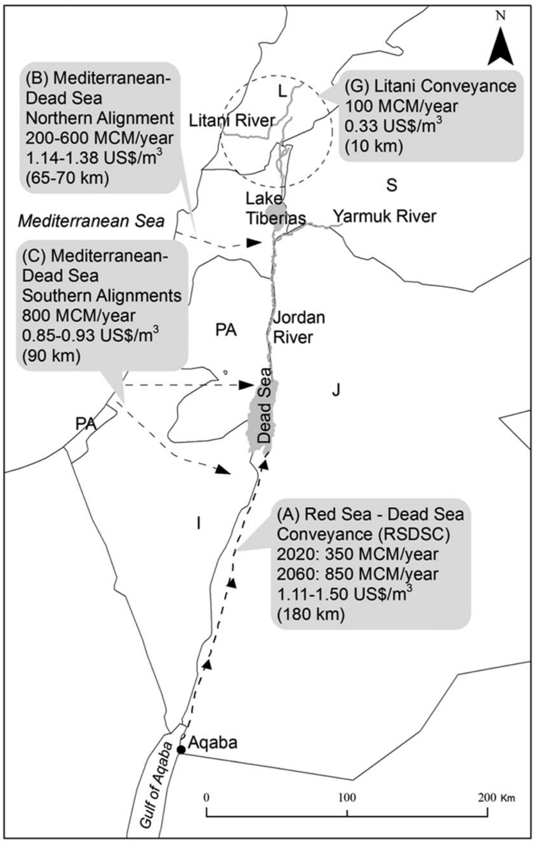
Note: (Pop. = Population; M = million). (a): deficits based on available natural renewable freshwater resources for each country, assuming a constant water demand of 230 m^3/capita/year. (b): deficits based on total available natural renewable fresh water resources in the lower Jordan River Basin equally distributed amongst the three riparians based on respective populations.

Aqaba coast (Red Sea), which is around 350 km away from the capital Amman, where more than 70% of the population reside. The Palestinians in Gaza and West Bank have access to around 28 MCM/year of spring water and around 246 MCM/year of groundwater, some desalinated water (4.7 MCM/year) and water purchased from the Israeli water company, Mekorot (63.5 MC/year) (PCBS, 2014). In Gaza, people resort to over-pumping from the coastal aquifer. As for the potential of developing further resources, the Palestinians face restrictions on accessing fresh water resources from the Mountain Aquifer and the JRB (Abu Zahra 2001, Dbaibes-Murad 2009) and do not have access to other sources, particularly in the land-locked West Bank.

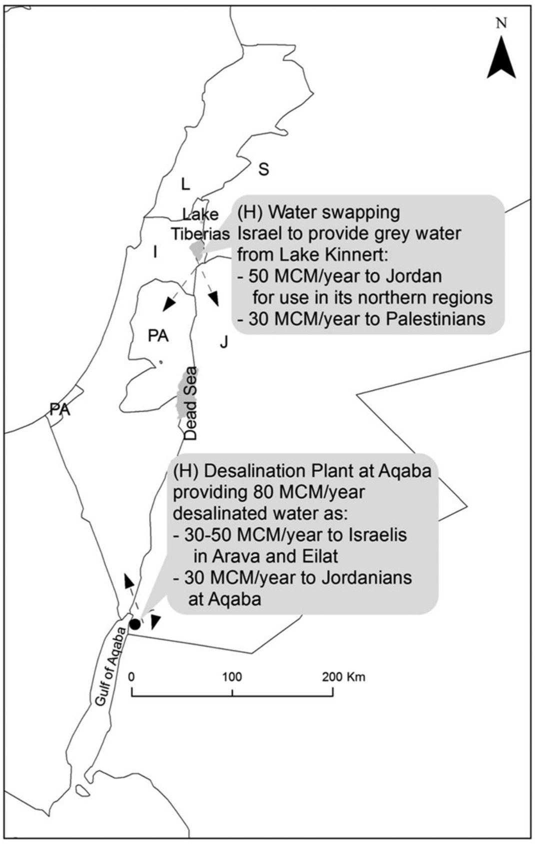
With increasing withdrawals from the JRB, the total inflow to the Dead Sea have dropped from the historical natural flow rate of ~1370 MCM/year to ~120 MCM/year in recent years (World Bank 2012a, Chen and Weisbrod 2016). As such, the levels of the Dead Sea have continuously declined from 397 m below sea level in 1970 to 423 m below sea level in 2010, resulting in a 24% shrinkage in its surface area (from 764 km^2 to 583 km^2) (Abu Ghazleh *et al.* 2011, World Bank 2012b). Even with its current rate of decline that is reported to be around 1 m/year (Abu Qdais 2008), its disappearance is not likely since increased salinities will reduce the amount of annual evaporation. It is anticipated that the Dead Sea will stabilize at a level of −550 m (surface area of 450 km^2) (Closson *et al.* 2010, Abu Ghazleh *et al.* 2011).

Declining water levels have resulted in adverse environmental consequences in the basin including a lower groundwater table within the Dead Sea basin, formation of sink holes and subsidence of existing infrastructure, loss of recreational value as well as potential loss of industrial development (mainly potash industry), disruption of the basin ecosystem with changes to the landscape and the loss of the cultural symbol of the Dead Sea region, and potential increase in incidence of dust storms with associated harm to fertile lands (Beyth 2007; Abu Qdais 2008, World Bank 2010, Abu Ghazleh *et al.* 2011, 2010).

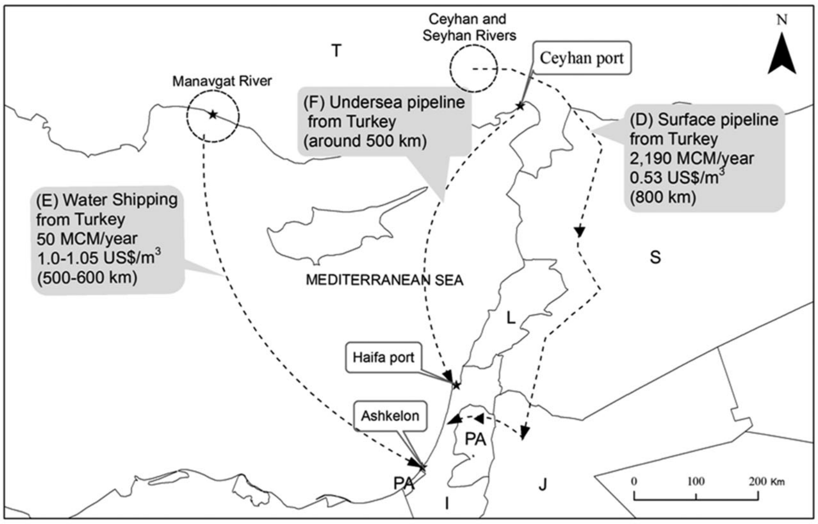
Additional water supplies are thus critical to meet essential water demands, to maintain the Dead Sea's level, and to eventually reverse the decreasing trend. Several alternatives have been put forth in the past decades to supply the Dead Sea and the JRB with 'new' water, including the construction of the Red Sea–Dead Sea Conveyance (RSDSC) that will be shared among Israel, Jordan, and the PA (Mohsen 2007; World Bank 2012a, 2012b, Comair *et al.* 2013); a canal extending from the Mediterranean Sea in Israel to the Dead Sea (Beyth 2007); diverting water from Turkey into the JRB (Mohsen 2007); diverting water from the Litani River Basin of Lebanon into the JRB (Shuval 2000); and an agreement



Mediterranean - Dead Sea Conveyance, Red Sea - Dead Sea Conveyance (RSDSC), and Litani Water Conveyance



Seawater desalination and gray water swapping



Water transport from Turkey to the region by shipping, surface and/or undersea pipelines

Figure 2. Illustration of conveyance routes of multi-country water supply alternatives.

Note: Water costs are based on 2012 references or have been standardized to the year 2012 using annual average Consumer Price Indices. I: Israel; J: Jordan; L: Lebanon; PA: Palestinian Authority; S: Syria; T: Turkey. References for alternatives A, B, & C: Allan et al. 2012; Beyth 2007, D: IPCRI 2010, E: IPCRI 2010; Ariyoruk 2003, G: Shuval 2000; H: Barnea 2013; Al-Khalidi 2015.

for a Red Sea desalination project in the south of Jordan at Aqaba coupled with swapping of water among Israel, Jordan, and PA from Lake Tiberias (Barnea 2013, Al-Khalidi 2015). A general layout of those various alternatives and their potential routes is illustrated in Figure 2 and a summary of each is provided in Table 1. Moreover with advancements in desalination technology, the development of national seawater desalination programmes for each riparian can serve as a source of new water supply (Table 1).

The objective of this paper is to compare the various regional and local water supply development projects in terms of preference for implementation to augment water supply in the riparian countries of the lower JRB. The comparison is carried out by ranking the preference for implementing the identified alternatives using multi-criteria decision analysis and taking various technical, economic, environmental, and political constraints into consideration.

2. Methodology

Multiple Criteria Decision Analysis (MCDA) is a tool for comparing alternatives (policies or projects) by using a standardized scale for evaluation criteria to reach a transparent and analytical decision (Kheireldin and Fahmy 2001, Hajkowicz and Collins 2007, Prato and Herath 2007, Hajkowicz and Higgings 2008, Yilmaz and Harmancioglu 2010, Mooney *et al.* 2012). A variety of MCDA techniques have been applied to rank or score water resources management alternatives with one commonly used technique being the Simple Additive Weighting (SAW) (Hajkowicz and Higgins 2008, Memariani *et al.* 2009). Several studies compared the performance of the SAW with other MCDA methods for ranking such alternatives. Their results have shown that there is a close agreement among these methods with no clear methodological advantage to any single technique (Karamouz and Zahraie 2003, Chowdhury and Rahman 2008, Yilmaz and Harmancioglu 2010). In fact, according to Zanakis *et al.* (1998), the SAW emerged as one of the best performers among a group of eight MCDA methods. Moreover, Hajkowicz and Higgins (2008) argued that the SAW approach is a relatively simple technique whose output is in strong agreement with other approaches. For any applied MCDA technique, the most sensitive step is the selection of decision options, evaluation criteria and performance measures (Karamouz and Zahraie 2003, Hajkowicz and Collins 2007, Hajkowicz and Higgins 2008, Yilmaz and Harmancioglu 2010). As such, this study used the SAW method to assess the proposed alternatives.

In this application of SAW, the formulated decision problem is to rank the identified water supply development alternatives (Table 1) for preference of implementation with respect to addressing the regional water deficit and enhancing cooperation in the lower JRB. The alternatives are evaluated against a set of eight criteria. Performance indicators are identified for the selected criteria along with a scoring system (Tables 2 and 3). Accordingly, scores are assigned to each alternative on each criterion (Table 4) and then multiplied by the importance weights for each criterion as defined by various scenarios (Table 5). The total score for each alternative is then computed by summing over all weighted criteria (Equation 1):

$$U_i = {}_{(j=1)}^{m} R_{(i,j)} W_j, \qquad (1)$$

where i = number of alternative being evaluated (from 1 to 10); j = number of evaluation criterion (from 1 to 8); U_i = overall score for i^{th} alternative, ranging between 0 and 5; $R_{i,j}$ = normalized score assigned to alternative i with respect to criterion j; and W_j = weight assigned to j^{th} criterion with the total value for all the criteria weights (W_j) set to one ($\sum_1^j Wj = 1$). Alternatives can thus be ranked based on the resulting scores (U_i), whereby a higher score represents a better ranking. Note that two alignments are proposed for the Mediterranean–Dead Sea project and thus each has been assessed independently.

2.1. Evaluation criteria

A set of eight comparative evaluation criteria was defined to account for technical, economic, environmental, water quantity, and political aspects commonly adopted by MCDA studies (Hajkowicz and Collins 2007). These criteria were evaluated based on published literature in relation to those development alternatives and for which the information is summarized in Table 1. In order to transform all the criteria into ordinal data, scores between 1 and 5 were used to measure the performance of each alternative. An explanation of each criterion performance indicator and scoring scale is presented in Table 2.

The technical criterion was used to evaluate the applicability of the proposed technology; the economic dimension was represented as the cost of cubic metre of water delivered to end-users. The annual water quantity supplied through each alternative is another important criterion used in the comparison. Projects able of providing larger volumes of 'new' water to the system are favoured, given the bleak deficits in the basin. Additional economic benefits accrued from such alternatives are not considered because it is expected that the additional water quantity will be used by the same population, for the same activities, and within the same target region. Moreover, evaluating the economic benefits resulting from large-scale developments requires programme-specific and detailed feasibility studies. As such, this study was confined to reported costs on a unit volume of water (US$/m^3).

In reflecting at the environmental performance of the alternatives, two criteria were selected: (1) the ability to address the declining level of the Dead Sea, and (2) the overall environmental impacts during the construction and operation phases. The overall environmental impact criterion was evaluated based on the potential level of influence on land degradation, terrestrial and/or marine ecosystems, energy consumption and associated carbon footprint, as well as based on whether the water quality supplied requires further treatment before distribution (Table 3). In general, water conveyance projects over long distances have been evaluated to cause medium to high impacts on various receptors, including biological, physical, social, agricultural, and archaeological. Those impacts are mostly temporary in nature during the construction phase with a few persisting during the operation phase (MWI 2004) but both can be mitigated or minimized with the adoption of proper environmental management measures. Moreover, energy requirements, and eventually the carbon footprint, of large-scale water transfer projects increases with distance and elevation (Shrestha 2010). Overall, the carbon footprint of water transfer remains smaller than those associated with various seawater desalination systems due to high-energy demand of the latter (Shrestha 2010, Liu *et al.* 2015). Still, environmental concerns associated with desalination extend beyond carbon emissions to impacts of seawater intakes on marine life and concerns with disposal of the concentrated brine (Cooley *et al.* 2013).

With respect to the political dimension, the success of any project will be a function of the conflict amongst riparians and controversies over the Euphrates–Tigris. Given the disputes between various stakeholders, the political dimension was assessed based on two criteria: (1) the number of riparian countries that will benefit from the additional water supply, and (2) the number of countries that are willing to support the project implementation. The final scores for the evaluated alternatives based on technical, environmental, political, and economic criteria are summarized in Table 4.

2.2. Weights and sensitivity analysis

Assignment of weights in MCDA is often considered a subjective process that can affect the reliability of the results. In an effort to reduce subjectivity, a sensitivity analysis on

Table 1. Feasibility and limitations of proposed water augmentation alternatives in the JRB countries.

Alternative	Proposed route	Beneficiary country (ies)[a]	New water quantity	Cost of water[b]	Expected life span	Feasibility	Limitations	Status
Multi-country water supply development alternatives								
RSDSC	From Red Sea shore at Aqaba City to the shores of the Dead Sea, strictly within Jordanian territories	Israel, Jordan, and PA	350–850 MCM/year (World Bank 2012a)	1.11–1.5 US$/m^3 (Allan *et al*. 2012)	∼40 years (Allan *et al* 2012)	Sustainable water source to the three beneficiaries. Stabilizes the Dead Sea level. Encourages cooperation. Power requirement partly subsidized by internal hydropower. Water quality suitable for direct use without further treatment.	Very high capital cost estimated at around 11 billion USD (World Bank 2012a; MWI 2016) and high cost of water to end-users. Overall medium environmental impacts expected on land and ecosystems even with implementation of an environmental management plan (World Bank 2012b). Energy intensive with a carbon footprint between 0.65 and 4.35 million tons of CO_2 per year for the time period 2020–2060 depending on various configurations (World Bank 2012a).	Underwent a feasibility and environmental impact assessment programme by the World Bank, but little progress has been achieved in realizing it due to financial constraints (MWI 2016)
Mediterranean–Dead Sea Canal	Two proposed alignments: Southern (90 km), and Northern (65–70 km). Both are from the Mediterranean Sea to the Dead Sea shore strictly within Israeli territories	Israel, Jordan, and maybe PA	Southern alignments: 800 MCM/year Northern alignment: 200–600 MCM/year (Beyth 2007)	Southern alignment: 0.85–0.93 US$/m^3 Northern alignment: 1.14–1.38 US$/m^3 (Allan *et al*. 2012)	Assumed to be ∼40 years similar to RSDSC	Sustainable water source to Israel as the main beneficiary and may serve as a sustainable source for Jordan. Only Southern alignment helps stabilize the Dead Sea level. Canal route options are shorter and cheaper than that of Red Sea–Dead Sea. Desalination cost is declining with advances in technology. Water quality suitable for direct use without further treatment.	Very high capital cost and high cost of water to end-users. Northern alignment does not address problem of declining Dead Sea level. As a large-scale desalination plant, serious environmental concerns are imperative with respect to marine ecosystem due to seawater intakes and brine disposal (Cooley *et al*. 2013). Desalination plants have high carbon footprints due to energy consumption (Shrestha 2010, Liu *et al*. 2015). High probability to face hegemony by Israel as manifested in Israeli sharing approach for other transboundary resources such as Mountain Aquifer, Jordan River, and Lake Tiberias. Not a solution to Jordan's serious water scarcity. Does not promote cooperation. Cannot attain international funding.	Has been abandoned due to economic infeasibility and international objection to funding the construction of such a large-scale alternative on a unilateral Israeli basis.

(*Continued*)

Table 1. Continued.

Alternative	Proposed route	Beneficiary country (ies)[a]	New water quantity	Cost of water[b]	Expected life span	Feasibility	Limitations	Status
Water transport from Turkey via surface pipeline, 'Mini Peace Line', from Seyhan and Ceyhan river basins in Mediterranean coast	From Seyhan and Ceyhan Rivers in Turkey through Syria to Jordan and PA over a distance of ~800 km	Israel, Jordan, PA, and Syria	2190 MCM/year (IPCRI 2010)	0.53 US$/m^3 (IPCRI 2010)	Not determined. Assumed to be similar to water shipping which is 20 years	Provides a large amount of water to Jordan and PA. Original plan can be expanded to include Israel. Encourages cooperation. Relatively acceptable cost of water to end-users. Large-scale water conveyance has a smaller carbon footprint than desalination plants (Shrestha 2010, Liu *et al.* 2015).	High capital cost at around 5 billion USD. Does not address the declining Dead Sea level. Large-scale conveyance projects have high ecosystem and land degradation impacts during construction and medium-level impacts during operation (MWI 2004). Subject to variability due to climate change influence on available freshwater resources. Hence, might not be reliable for long-term periods such as 20 years. Subject to political conflict. Pipeline to pass in Syria that has disputes with Turkey over water and is engulfed in civil war. Also, anticipated Syrian objection to any form of cooperation with Israel. Fresh water may require further treatment before distribution.	Currently not possible to bring Syria to participate on an alternative with Israel and Turkey due to the Israeli occupation of the Syrian Golan Heights and the involvement of Turkey in the ongoing civil war.

Water transport from Turkey by shipping from Manavgat river basin	From Manavgat River in Turkey to Ashkelon port in Israel over a shipping distance of 500–600 km	Israel and maybe PA	50 MCM/year	1.0–1.05 US$/m^3 (Ariyoruk 2003, IPCRI 2010)	20 years (IPCRI 2010)	Facilities for water loading at Turkey have already been built. Reasonable shipping distance. Technology may be replicated as a solution for the water scarcity in Gaza. Opportunity for Israel to pump less water from Lake Tiberias and in turn allow more water flow in the Jordan River and into the Dead Sea.	More expensive than desalination due to transportation costs with a relatively high cost of water to end-users. Addresses only part of the current water shortage experienced by Israel but not by Jordan and the PA. Does not address the problem of the declining Dead Sea. Unsustainable solution that draws on the water resources of another basin. Low-level environmental impacts anticipated on terrestrial-marine ecosystems with potential land degradation. Carbon footprint from shipping as a medium-level impact since it is greater than that associated with conveyance but less than carbon footprint of large-scale desalination plants. Subject to variability due to climate change influence on available freshwater resources. Hence, might not be reliable for long-term periods of 20 years. Political tensions that arise and subside between Israel and Turkey hamper such an arrangement in the near future. Fresh water may require further treatment before distribution.	The Israeli-Turkish agreement signed in March 2004 to purchase water for 20 years was cancelled due to the high cost of delivered water. Still, the idea could be revived on a commercial scale as regional water shortages become more severe and political relations improve.

(*Continued*)

Table 1. Continued.

Alternative	Proposed route	Beneficiary country (ies)[a]	New water quantity	Cost of water[b]	Expected life span	Feasibility	Limitations	Status
Water transport from Turkey via undersea pipeline from Seyhan and Ceyhan river basins	From Turkey's Mediterranean port of Ceyhan to the port of Haifa over a distance of ∼500 km	Israel	Not determined. Assumed to be between 100 and 500 MCM/year.	Not reported, but can be safely assumed to be high, given the alternative's high capital cost and conveyance distance.	Not determined. Assumed to be similar to water shipping at 20 years	Additional source of water for Israel. Enhanced bilateral relations between Israel and Turkey. Not influenced by Israeli political disputes with neighbouring Arab countries. May be an opportunity for Israel to pump less water from Lake Tiberias, hence allowing more water flow in the Jordan River and into the Dead Sea. Being similar to large-scale overland water conveyance, an undersea water conveyance pipeline is assumed to have smaller carbon footprint than desalination plants.	High capital cost of 2.5–4 billion USD. No estimated water cost. The proposed investment range indicates a relatively high cost per cubic metre of water. Technical concerns regarding availability of pipes that would be able to withstand the pressure exerted by the seawater depth between Turkey and Israel. Addresses only part of the current water shortage being experienced by Israel but not by Jordan or the PA. Does not address the declining Dead Sea. Similar to large-scale overland conveyance projects, the undersea pipeline is anticipated to have high marine ecosystem impacts during construction, some of which may persist during the operation phase. Subject to variability due to climate change influence on available freshwater resources. Hence, might not be a reliable option for a long-term period of 20 years. Freshwater may require further treatment before distribution.	In September 2013, Israel declared the appointment of a team of experts to advance the negotiations for this undersea infrastructure corridor.

Litani River Water Conveyance	From Litani River of Lebanon to Lower JRB	Israel, Jordan, and PA	100 MCM/year	0.33 US$/m^3 (Shuval 2000)	25–30 years (Gotlibovski 1996)	Allows for additional water flow within the Jordan River. Encourages cooperation. Relatively low cost of water end-users. Large-scale water conveyance has a smaller carbon footprint than desalination plants (Shrestha 2010, Liu *et al.* 2015).	Lebanon has been experiencing water shortage and needs all its water resources. Does not address the declining Dead Sea level. As a large-scale conveyance, has high ecosystem and land degradation impacts only during construction. Operation phase has medium impact (MWI 2004). Subject to variability due to climate change influence on available freshwater resources. Impeded by the existing political conflict between Lebanon and Israel. Additional delivered water is not enough to bridge an appreciable percentage of the water gap faced by the lower JRB. The Litani River water requires treatment before distribution.	Considered non-viable since Lebanon has been experiencing water shortage and already started implementing the diversion projects of the Litani and Awali rivers to Beirut and South Lebanon. Proposal not discussed among riparians and only suggested by Israel.
'Red Sea Desalination' as 'Phase I' of the RSDSC and water swapping from Lake Tiberias	Agreement signed in 2013 among Israel, Jordan and PA as 'Phase I' of the RSDSC. Jordan to desalinate water through 'Red Sea Desalination' project at Aqaba and supply the water to southern Israel in return for transfering water from Lake Kinnert to Jordan and PA. Brine to be discharged in the Dead Sea in a 205-km pipeline (MWI 2016).	Israel, Jordan, and PA	140–160 MCM/year. Desalination: 80–100 MCM/year: 40 MCM to Israel and the rest to Jordan at Aqaba. Water swap: Israel provides 50 and 30 MCM/year of Lake Tiberius water to Jordan and PA respectively. (Barnea 2013; Al-Khalidi 2015)	Desalination: Not determined, but should not exceed reported ranges of desalinated water cost since no conveyance over large distances is needed to reach end-users. Water swap: Jordan to buy Tiberias water from Israel at 0.42 US$/m^3 (MWI 2016)	Assumed at ∼40 years similar to RSDSC	Sustainable additional source of water to Israel, Jordan, and PA. Encourages cooperation and enhanced relations between Israel, Jordan, and PA. Not influenced by Israeli political disputes with other neighbouring Arab countries. No estimated water cost. However, it is considered to be a relatively acceptable cost of water to end-users as desalination cost is declining with advances in technology. Desalination project estimated to cost 900 MUSD (Barnea 2013).	Contributes to Jordan water resources but is not a solution to its serious water scarcity. Partly addresses the declining level of the Dead Sea by providing an amount of brine for disposal into the Dead Sea (∼300 MCM/year), which is not adequate to revert its level. Desalination plants have serious environmental concerns with respect to marine ecosystem and potential impacts of seawater intakes and brine disposal (Cooley *et al.* 2013). The desalination plant will be energy intensive and will have a high carbon footprint (Shrestha 2010; Liu *et al.* 2015). Additional delivered water is not adequate to bridge an appreciable percentage of the water gap faced by the lower JRB. Grey water requires further treatment before distribution.	The implementation of the Red Sea Desalination Project at Aqaba has been initiated and prequalification of companies, investors and for its development is under consideration a build-operate-transfer (BOT) contract (MWI 2016).

(*Continued*)

Table 1. Continued.

Alternative	Proposed route	Beneficiary country (ies)[a]	New water quantity	Cost of water[b]	Expected life span	Feasibility	Limitations	Status
Local Desalination Programmes								
Jordan Red Sea Project (JRSP) for seawater desalination	Water conveyance and seawater desalination from Red Sea at Aqaba to the Dead Sea and Amman. Excess seawater and desalination brine to be discharged to the Dead Sea.	Mainly Jordan with potential to sell water but unlikely	930 MCM/year (GoJ 2011)	2.0 US$/m^3 of which ~1.5 US$/m^3 are estimated for conveying and pumping water from Aqaba to Amman (Allan *et al.* 2012)[c]	Assigned a 40–45 years development period (GoJ 2011)	Sustainable water source to Jordan. Stabilizes the Dead Sea level. 18% of the project's power requirement will be provided by internal hydropower (MWI 2016). Water quality suitable for direct use without further treatment.	Very high capital cost at around 11.9 billion USD (GoJ 2011) and high cost of water to end-users. Overall medium environmental impacts on land and ecosystems with implementation of environmental management plans (World Bank 2012b). Energy intensive as it requires 995 MW/year of electricity (MWI 2016), which implies that the project will have a very high carbon footprint.	Implementation of the 'Red Sea Desalination' is considered as Phase I of the JRSP.
Local desalination programmes for Gaza of PA, Israel, Lebanon, and Syria	Local desalination plants situated along coastal zones of Gaza Strip, Israel, Lebanon, and Syria Israel has already established its coastal desalination programme.	Israel, Lebanon, PA, and Syria separately benefits from implementing such local initiatives	Israel coastal desalination programme to provide 750 MCM/year by 2020 (Tenne 2010). Each local desalination programme assumed to be able to provide a similar volume.	0.59 US$/m^3 (Chen *et al.* 2015)	Israel's desalination plants are under BOT contracts for 25 years (Tenne 2010). Therefore, it can be assumed that such programmes have a life span of ~30 years.	Individually implemented desalination plants constitute a sustainable water source to the beneficiaries. Desalination cost is declining with advances in technology. Water quality suitable for direct use without further treatment. Acceptable cost of water to end-users.	High capital cost constrained by budgets of individual countries. Individual local desalination plants in Lebanon and PA do not address problem of declining Dead Sea level. Desalination plants are associated with serious environmental concerns with respect to marine ecosystem due to seawater intakes and brine disposal (Cooley *et al.* 2013). Desalination plants are established to have quite high carbon footprint due to large energy consumption (Shrestha 2010, Liu *et al.* 2015). Individual local desalination programmes do not promote cooperation.	Israel has already established its coastal desalination programme. For Gaza, Lebanon, and Syria, local desalination plants are proposed for evaluation.

[a]*'Beneficiary Countries'* refers to countries who will be receiving water shares from a development alternative.
[b]All water costs are based on 2012 references or have been standardized to the year 2012 using the annual average Consumer Price Indices.
[c]Desalination cost exceeded by far the \$0.59/m^3 indicated by Chen *et al* (2015) due to a larger amount of energy needed to pump the water from below sea level to regions of water demand at higher elevations of exceeding 1000 metres above sea level.

Table 2. Criteria, performance indicators, and scoring system for comparative assessment of proposed alternatives.

Dimension	Criteria (j)	Symbol	Performance indicator	Scoring system for various criteria using a scale of 1 to 5: 1	2	3	4	5
Technical	Feasibility	C1	Alternative is based on a simple and well-established technology	Not feasible	–	Feasible but not readily applied	–	Feasible and readily applied
Economic	Cost of water	C2	Cost of water to end-users (US$/m^3)	> 1.0	0.8–1.0	0.6–0.8	0.4–0.6	0.2–0.4
Environmental	Dead Sea level	C3	Ability to revert decline of Dead Sea level	No	–	Addresses the declining level Partially	–	Yes
	Potential environmental impacts	C4	Potential environmental impacts (EI) during construction and operation in terms of ecosystem impacts, land deterioration, energy consumption and associated carbon footprint, as well as water quality based on total scores as shown in Table 3.	17–20 (Very high EI)	13–16 (High EI)	9–12 (Medium EI)	5–8 (Low EI)	1–4 (Very Low EI)
Political	Political will to support project implementation	C5	Countries willing to support implementation	None	Israel or at least one riparian	Israel and one riparian	Israel and two riparians	Israel and three or more riparians
	Promotion of regional cooperation	C6	Number of riparian countries benefiting from the additional water to be provided by the proposed alternative	One beneficiary The project has the potential to face hegemony.	Two beneficiaries	Three beneficiaries	Four beneficiaries	Five beneficiaries
Water Supply	Water quantity	C7	Potential quantity of fresh water to be supplied by the alternative	< 100 MCM/year	100–500 MCM/year	500–750 MCM/year	750–1000 MCM/year	> 1000 MCM/year
	Reliability	C8	Projected life-time (number of years) of proposed alternative	< 10 years	10–15 years	15–25 years	25–30 years	> 30 years

weight assignment was performed using two approaches. Initially, eight scenarios were defined in which weights were assigned to the criteria to achieve a different set of social, political, technical, and environmental targets (Table 5). The ranking of alternatives with regard to each scenario was examined accordingly.

The second approach evaluated the sensitivity of rankings to the weight assignment under each scenario. This was accomplished by varying the weight of the most prominent criterion under each scenario from 0.1 to 0.5 at 0.01 increments and readjusting the weights of the other criteria to maintain a total sum equal to one ($\sum_1^j Wj = 1$).

3. Results and discussion

The rankings of proposed alternatives by scenario and corresponding weight are illustrated in Figure 3. Local desalination programmes appear to be less attractive when compared to the adoption and implementation of multi-regional alternatives, specifically the RSDSC, 'Mini peace pipeline', the southern alignment of the Mediterranean–Dead Sea Canal, the 'Red Sea' desalination and grey water agreement alternatives. This is largely due to the failure of local desalination plants to revert the declining Dead Sea level and their limited ability to enhance cooperation between multi-lateral parties.

When multi-country alternatives were considered based on an equal weights scenario (S1), the RSDSC appears most favourable followed by water transport from Turkey via surface pipelines. The RSDSC ranked first due to its ability to provide a reliable and sustainable supply of water for three most stressed beneficiaries (Israel, Jordan, and the PA). Such a supply would reduce the water deficit substantially for Jordan and contribute towards enhancing the water supply for Israelis and Palestinians. It also presents an opportunity for enhancing regional cooperation and a means for reverting the declining level of the Dead Sea. The seawater desalination and grey water swapping ranked third given the high reliability of the water supplied with its ability to promote cooperation amongst Israel, Jordan, and the PA as well. The southern alignment of the Mediterranean–Dead Sea Canal ranked fourth mainly due to the quantity of water it delivers and its ability to revert the declining level of the Dead Sea. The two least preferable multi-country options under scenario (S1) were water shipping and the undersea pipeline from Turkey. These options propose delivering water to Israel with no potential contribution to resolving the problem of the declining Dead Sea, thus lacking a regional scope (IPCRI 2010). Some might argue that once Israel receives additional water supplies it might accept to relinquish JRB waters by releasing some flow from Lake Tiberias for use by Jordan and PA or for having more flow into the Dead Sea. However, there are no guarantees to this effect. Israel has already started a desalination programme along its Mediterranean Coast to increase its water supplies, but did not consider releasing JRB waters under its control. Even when water quantity is emphasized as a major objective (S2), those two alternatives remain the least favourable. A noticeable change under S2 (water quantity) is that the surface pipeline from Turkey replaces RSDSC at the first rank mainly due to the fact that the proposed 'Mini Peace pipeline' from Turkey will supply three parties with the largest quantity of water among all proposed alternatives. Still, this option

Table 3. Sub-criteria and scale used for evaluating potential environmental impacts associated with proposed water supply development alternatives.

Sub-criteria for environmental criterion	Evaluation scale of potential environmental impacts		
	High (5)	Medium (3)	Low (1)
Terrestrial and/or marine ecosystem impact	High adverse impact on terrestrial/ marine ecosystem 5	Medium adverse impact on terrestrial/ marine ecosystem 3	Temporary disturbance to terrestrial/ marine ecosystem 1
Land deterioration impact	High adverse impact on land deterioration 5	Medium adverse impact on land deterioration 3	Temporary land disturbance 1
Energy consumption and associated carbon footprint	High energy consumption and associated carbon footprint 5	Medium energy consumption and associated carbon footprint 3	Low energy consumption and associated carbon footprint 1
Water quality delivered by the proposed alternative	Water requires further treatment 5	Water requires mixing before use 3	High quality water to end-users. No need for further treatment. 1

Table 4. Performance matrix for proposed alternatives based on technical, environmental, political, and economical criteria.

Alternatives	Scores ($R_{i,j}$)[a]								
	C1	C2	C3	C4	C5	C6	C7	C8	**Total**
RSDSC	5	1	5	3	4	3	4	5	**30**
Mediterranean–Dead Sea Canal, northern alignment	5	1	1	3	2	1	3	5	**21**
Mediterranean–Dead Sea Canal, southern alignments	5	2	5	3	2	1	4	5	**27**
Water Transport from Turkey via surface pipelines from Seyhan and Ceyhan river basins in Mediterranean coast	5	4	1	3	3	5	5	3	**29**
Water Transport from Turkey by Shipping from Manavgat river basin	3	1	1	4	2	1	1	3	**16**
Water Transport from Turkey via undersea pipelines from Seyhan and Ceyhan river basins in Mediterranean coast	3	2	1	3	2	1	2	3	**17**
Litani River Water Conveyance	5	5	1	2	4	1	2	4	**24**
'Red Sea Desalination' and grey water swapping	5	4	3	2	4	3	2	5	**28**
Jordan Red Sea Project (JRSP) for desalination	5	1	5	3	2	1	4	5	**26**
Local desalination programmes for Gaza of PA, Israel, Lebanon, and Syria	5	4	1	3	1	1	4	5	**24**

[a] C1: Technical feasibility C2: Cost of water, C3: Dead Sea level, C4: Potential environmental impacts, C5: Political support, C6: Promotion of regional cooperation, C7: Water quantity, and C8: Reliability

Table 5. Different sets of weights assigned to the evaluation criteria under all scenarios.

Scenario and Emphasis	Description	Assigned Weights (W_j) to Performance Indicators C1–C8[a]							
		C1	C2	C3	C4	C5	C6	C7	C8
S1 – Equal Weights	Assigns uniform weights to all criteria in order to indicate equal importance.	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
S2 – Water Quantity	Assigns a weight of 30% to quantity of water to be supplied to riparian countries. The remaining 70% is equally divided between remaining criteria.	0.100	0.100	0.100	0.100	0.100	0.100	0.300	0.100
S3 – Cooperation	Considers cooperation as a very significant aspect of a regional water supply project and assigns it 30% of criteria weight. The remaining 70% is equally divided between the remaining criteria.	0.114	0.114	0.114	0.114	0.114	0.200	0.114	0.114
S4 – Water Cost	Considers cost of water to end-users as the most important aspect and assigns it 30% of criteria weight. The remaining 70% is equally divided between remaining criteria.	0.100	0.300	0.100	0.100	0.100	0.100	0.100	0.100
S5 – Political Will	Considers political will to support project implementation as the most important criterion for success of regional water project and hence gives it 30% of criteria weight. The remaining 70% is equally divided between the remaining criteria.	0.100	0.100	0.100	0.100	0.300	0.100	0.100	0.100
S6 – Dead Sea level and environment	Considers environmental protection and reverting the decline in the Dead Sea level as the most important goal of any regional water development alternative and assigns accordingly 30% of importance to each of those two criteria. The remaining 70% is equally divided between the remaining criteria.	0.117	0.117	0.150	0.150	0.117	0.117	0.117	0.117
S7 – Political Will and Cost	Considers political will to support project implementation and the cost of water as the most important criteria for success of regional water project and hence gives them 40% of criteria weight. The remaining 60% is equally divided between the remaining criteria.	0.100	0.200	0.100	0.100	0.200	0.100	0.100	0.100
S8 – Water cost and environmental impacts including the Dead Sea level	Considers cost of water and the alternatives potential environmental impacts including their role in reverting the decline in the Dead Sea level as the most important criteria for success of a regional water project and hence gives them 45% of criteria weight. The remaining 55% is equally divided between the remaining criteria.	0.110	0.150	0.150	0.150	0.110	0.110	0.110	0.110

[a] C1: Technical feasibility, C2: Cost of water, C3: Dead Sea level, C4: Potential environmental impacts, C5: Political support, C6: Promotion of regional cooperation, C7: Water quantity, and C8: Reliability.

is riddled with political objections (mainly the Iraqi concerns) that although the source of transferred water is not the Euphrates and Tigris, Turkey may compensate the transferred water by relying on the Euphrates and Tigris basin. Moreover, if Turkey is capable of transferring water for other countries, then this implies that it is storing more water than needed and thus the shares its downstream riparians along the Euphrates and Tigris could still be made larger (Kirschner and Tiroch 2012). Another change is that the southern alignment of the Mediterranean–Dead Sea Canal is rendered more favourable when compared to the seawater desalination and grey water swapping agreement.

In S3, which emphasizes promotion of cooperation, the RSDSC and 'Mini Peace pipeline' ranked equally as best alternatives, followed by the agreement for seawater desalination and grey water swapping. Note that although the southern alignment of the Mediterranean–Dead Sea Canal also involves cooperation among three riparians, it ranked fourth under S3 (cooperation) mainly due to the high probability that this option might face control by Israel as manifested in the Israeli sharing approach for other transboundary resources such as the Mountain Aquifer, Jordan River and Lake Tiberias and hence it is not an alternative that promotes cooperation as exhibited

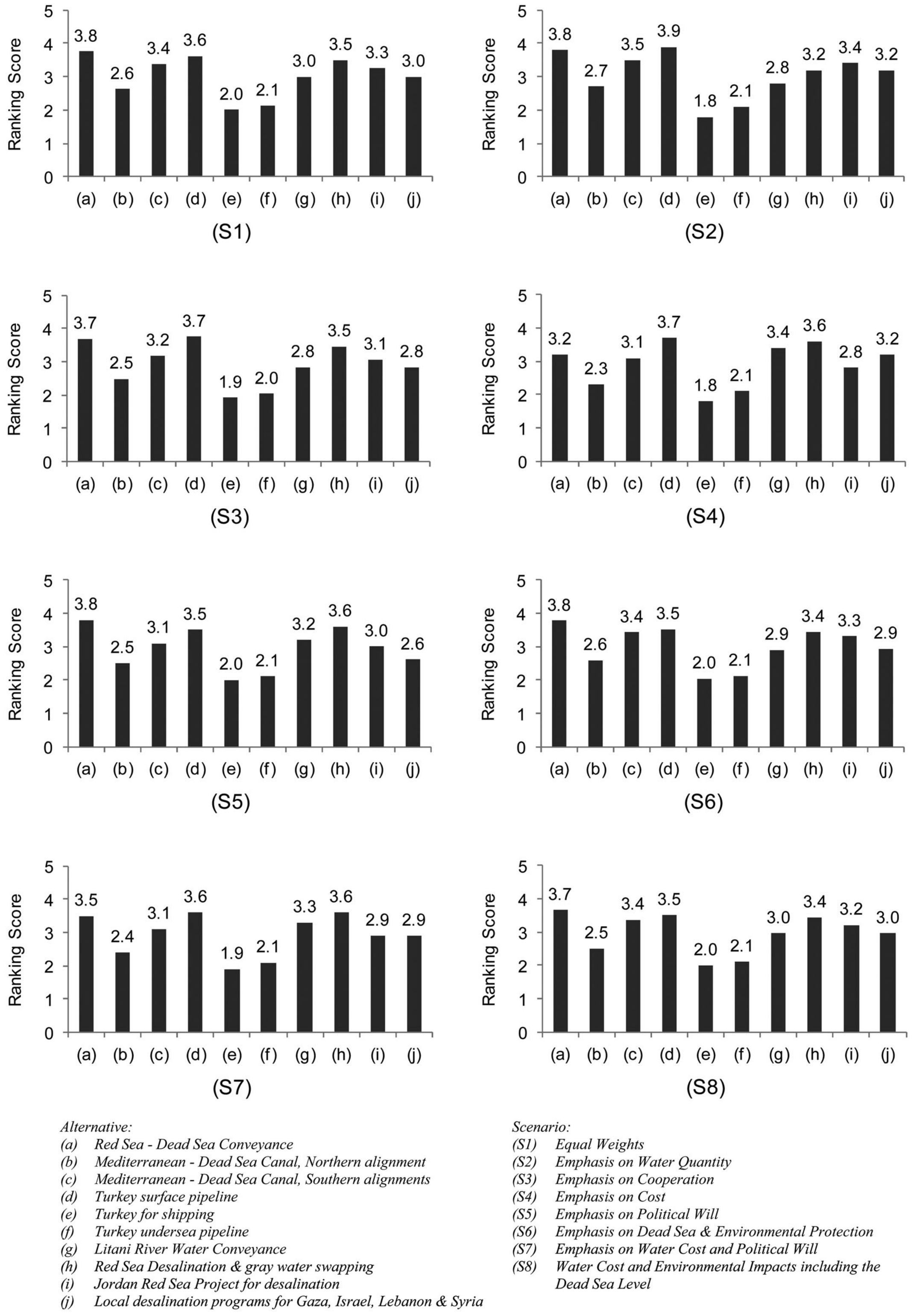


Figure 3. Assessment results for various scenarios of proposed large-scale regional water supply alternatives.

by the reluctance of international funding to support the alternative.

The most preferred option under S4 (water cost) is the 'Mini Peace pipeline' from Turkey. The RSDSC dropped down to fourth rank, behind the agreement for seawater desalination and grey water swapping at second place and the Litani River Water Conveyance as third. By emphasizing water cost, the scenario reflects the financial burden of implementing the RSDSC alternative. While the Litani River water conveyance (\$0.33/m^3) seems to be cheaper and require shorter transport distances, the Turkish 'Mini peace pipeline' delivers a higher quantity of water for an acceptable increase in cost (\$0.53/m^3). Moreover, the proposed amount of 100 MCM/year to be provided by the Litani River water conveyance is considered to be a minimal contribution to the water deficit faced by lower riparians of the JRB and even this amount is not possible to transfer from the Litani river because existing resources cannot meet the demand in that basin.

The RSDSC emerges again as the most preferred option followed by a seawater desalination and grey water swapping agreement under S5, which emphasizes political will for implementation. Each of Israel, Jordan, and the PA has expressed their agreement on the RSDSC. Although the Israelis favour the Mediterranean alignments (Closson *et al.* 2010, Gonce and Brendzel 2010), they supported the RSDSC (Beyth 2007, Sharp 2008). This may be attributed to the lack of international support to their preferred alignments and their desire to promote an image of peaceful cooperation. Similarly, the three parties (Israel, Jordan, and PA) have already agreed over the seawater desalination and grey water swapping option. Likewise, when the Dead Sea and environmental protection are emphasized (S6), the RSDSC remains to be the better option to promote those objectives.

In S7, under which cost and political will are emphasized, the 'Mini Peace pipeline' and the agreement for seawater desalination and grey water swapping ranked equally at first place followed by the RSDSC at second. Under the last scenario (S8), which emphasizes cost and environmental objectives, the RSDSC ranked first followed by the 'Mini Peace pipeline'. The southern alignment of the Mediterranean–Dead Sea Canal and the agreement for seawater desalination and grey water swapping were tied at third place.

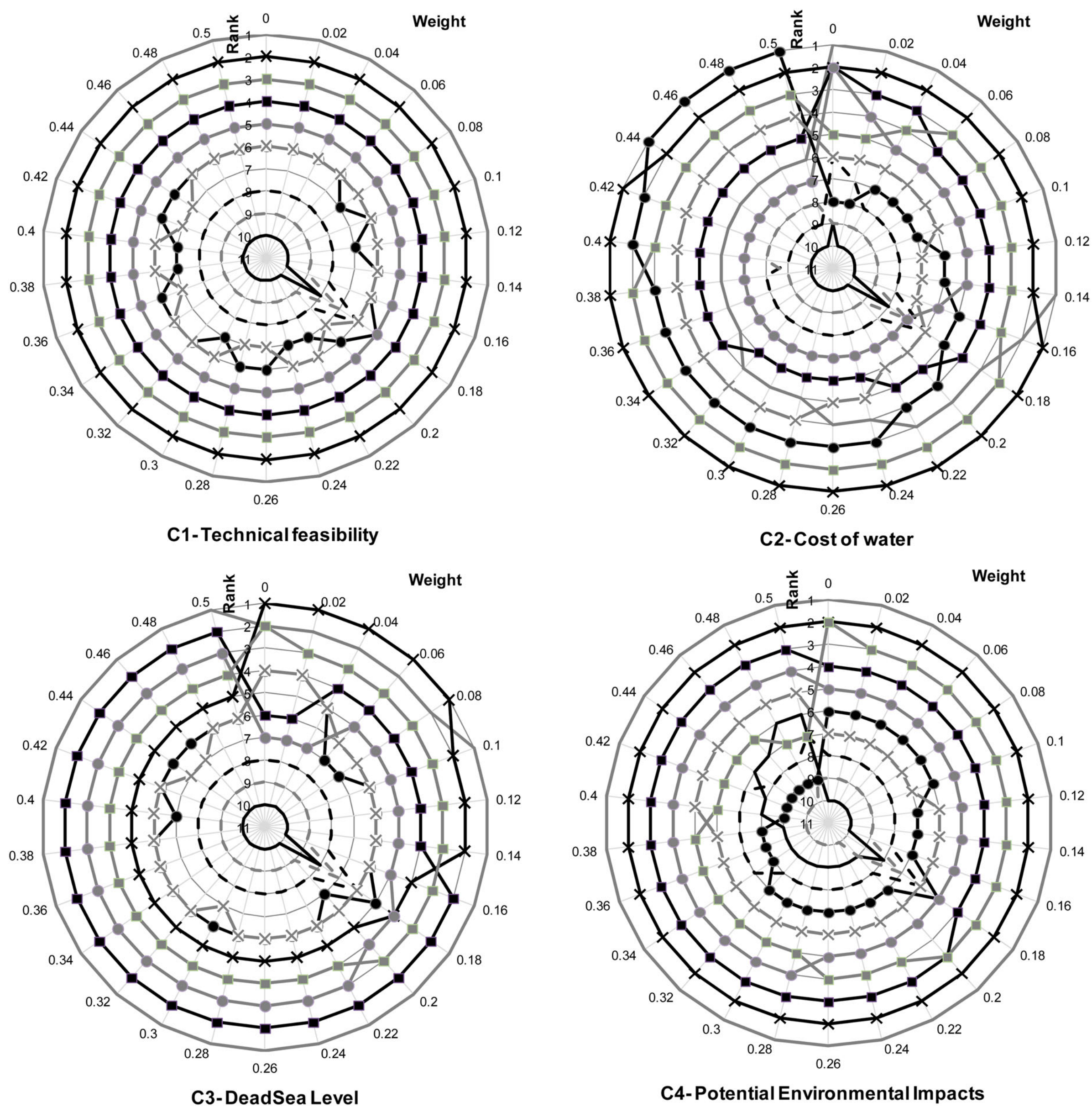
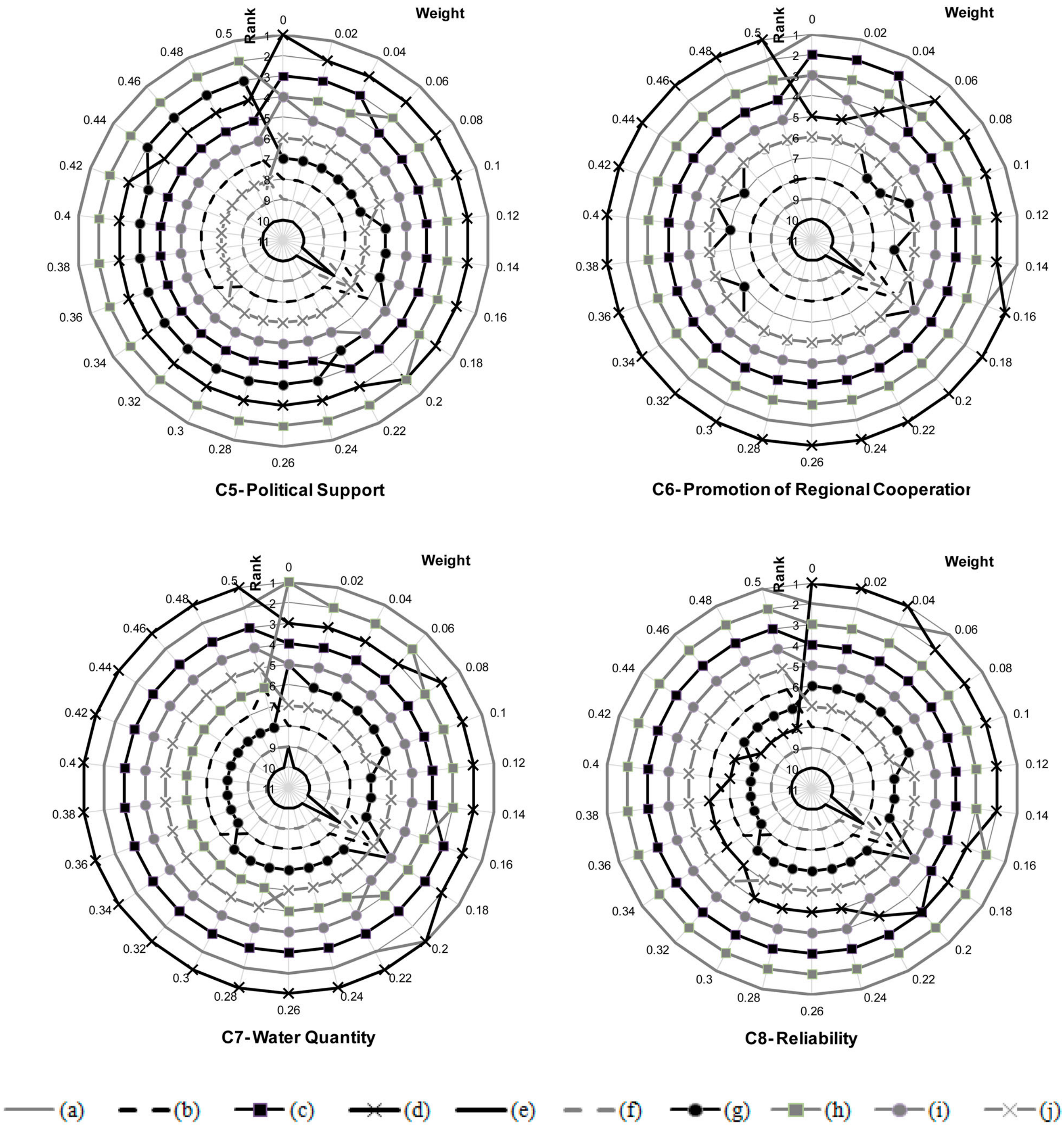


Figure 4. Sensitivity analysis results for varying criteria weights between 0 and 0.5.



Alternative:
(a) = Red Sea - Dead Sea Conveyance
(b) = Mediterranean - Dead Sea Canal, Northern alignment
(c) = Mediterranean - Dead Sea Canal, Southern alignments
(d) = Turkey surface pipeline
(e) = Turkey for shipping
(f) = Turkey undersea pipeline
(g) = Litani River Water Conveyance
(h) = "Red Sea Desalination" and gray water swapping
(i) = Jordan Red Sea Project for desalination
(j) = Local desalination programs for Gaza of PA, Israel, Lebanon and Syria

Sensitivity Analysis:
Varying weight for criterion while all else held uniformly equal
(1) Technical Feasibility
(2) Cost of Water
(3) Dead Sea Level
(4) Environmental Impacts
(5) Political Will
(6) Regional Cooperation
(7) Water Quantity
(8) Reliability

Figure 4. Continued.

The outcomes of the overall preference ranking for the water supply development alternatives in the lower JRB revealed the significance of the cost of water, promotion of cooperation and reliability of water supply in selecting the best alternative. The RSDSC has been the preferred option except for cost. Though desalination cost is declining rapidly with advancements in technology, the RSDSC has been associated with a high water cost due to the need to pump the desalinated water from the shores of the Dead Sea, which is below sea level, to Amman city, which is at around 1000 metres above sea level.

Figure 4 depicts the changes in rankings of alternatives as the weight of each criterion was varied from 0 to 0.5. In the figure, concentric circles are the y-axis indicating the rank of various alternatives (between 1 and 10), and the numbers appearing along the border of the concentric circles are the weights assigned to the criterion under consideration. As such, for example the concentric circles for technical feasibility (C1) imply that the 'Mini Peace pipeline' ranks at '1' and the RSDSC ranks at '2' irrespective of the weight assigned for C1, whereas the sensitivity analysis for water cost (C2) shows that if C2 is assigned a weight greater than 14%, the RSDSC will move from the first circle indicating rank '1' to the second circle indicating rank '2' favouring the 'Mini Peace pipeline' at rank '1'. The results indicate that the rankings are relatively robust to criteria of technical feasibility, potential environmental impacts, and political support. They are sensitive to water cost, Dead Sea level, cooperation, and water quantity and reliability. If water cost is assigned more than 14% of the criteria weight, then the RSDSC is outranked by the surface pipeline from Turkey. Similarly if stabilizing the Dead Sea level is assigned less than 10% of the total weight or reliability is provided 5%, the RSDSC is outranked by the surface pipeline from Turkey. The latter gains the highest preference when 20% or more of the criteria weight is assigned to water quantity or when 16% or more is assigned to promotion of regional cooperation. The rankings are thus more sensitive to factors relating to water cost, Dead Sea level, promotion of regional cooperation, as well as water quantity and reliability. However, the criterion on Dead Sea is considered as a significant requirement for any developmental water supply option targeting the lower JRB and, hence, is not anticipated to be disregarded in near- or long-term decision-making, and the simulated scenarios reflect that the sensitivity of the RSDSC to some criteria is balanced by its robustness to the other remaining criteria.

4. Conclusions

Conflicts over shared water resources are unlikely to be resolved without fulfilling the water demands of riparians. Water stress within the lower JRB riparians is continuously increasing with an inevitable need to develop new water supplies. Several regional water development alternatives were explored to alleviate these shortages. While the implementation of such alternatives is anticipated to serve mutual long-term interests and encourage regional collaboration, it is unlikely that all will be implemented. Identifying the most promising of these alternatives involves transcending the simple notions of quantity and quality to include social, environmental, and political considerations. The RSDSC emerges as a favourable and comprehensive option in this context towards cooperation over water resources and saving the Dead Sea.

Note

1. Israel, Jordan, Lebanon, PA and Syria.

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