emeraldinsight

Management of Environmental Quality: An International Journal

Water demand elasticities under risk conditions

Jamal Mousa Shamieh, Ihab Hanna Sawalha, Amer Z. Salman, Emad K. Al-Karablieh, Mohammad A. Tabieh, Hussain F. Al-Qudah, Osama O. Jaara,

Article information:

To cite this document:
Jamal Mousa Shamieh, Ihab Hanna Sawalha, Amer Z. Salman, Emad K. Al-Karablieh, Mohammad A. Tabieh, Hussain F. Al-Qudah, Osama O. Jaara, (2018) "Water demand elasticities under risk conditions", Management of Environmental Quality: An International Journal, Vol. 29 Issue: 1, pp.148-164, https://doi.org/10.1108/MEQ-10-2016-0080
Permanent link to this document:
https://doi.org/10.1108/MEQ-10-2016-0080

Downloaded on: 03 January 2018, At: 07:47 (PT)
References: this document contains references to 39 other documents.
To copy this document: permissions@emeraldinsight.com
The fulltext of this document has been downloaded 25 times since 2018*
Access to this document was granted through an Emerald subscription provided by emerald-srm:492215 []

For Authors

If you would like to write for this, or any other Emerald publication, then please use our Emerald for Authors service information about how to choose which publication to write for and submission guidelines are available for all. Please visit www.emeraldinsight.com/authors for more information.

About Emerald www.emeraldinsight.com

Emerald is a global publisher linking research and practice to the benefit of society. The company manages a portfolio of more than 290 journals and over 2,350 books and book series volumes, as well as providing an extensive range of online products and additional customer resources and services.

Emerald is both COUNTER 4 and TRANSFER compliant. The organization is a partner of the Committee on Publication Ethics (COPE) and also works with Portico and the LOCKSS initiative for digital archive preservation.

*Related content and download information correct at time of download.

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/1477-7835.htm

Received 25 October 2016
Revised 18 January 2017
16 March 2017
18 April 2017
Accepted 18 April 2017

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Water demand elasticities under risk conditions

Jamal Mousa Shamieh and Ihab Hanna Sawalha
Department of Risk Management, American University of Madaba, Amman, Jordan
Amer Z. Salman, Emad K. Al-Karablieh, Mohammad A. Tabieh and Hussain F. Al-Qudah
Department of Agricultural Economics and Agribusiness, The University of Jordan, Amman, Jordan, and
Osama O. Jaara
Department of Risk Management, American University of Madaba, Amman, Jordan

Abstract

Purpose – The purpose of this paper is twofold: first, to estimate the water demand elasticities using a parametric linear programming (LP) model to provide an insight into the accurate and flexible pricing policy of irrigation water in the Jordan Valley; and second, to highlight key risk aspects, related to water demand, which are likely to impact the community.

Design/methodology/approach – A parametric LP model was used in this research. Primary and secondary data were collected.

Findings – Results revealed that the demand elasticity is high in Spring and Summer than in Fall and Winter, meaning that during Spring and Summer farmers are willing to forgo larger amounts of water than in other months. This is because of areas planted during Spring seasons are much less than those of Autumn and Winter.

Practical implications – The Jordan Valley suffers from water scarcity risk, and consequently the area to be planted is not fully utilized, leading to lower cropping intensities. Responsible authorities in Jordan need to address these issues and propose proper solutions in order to reduce further escalation of this risk and subsequent impact on local communities. Insight into the value of water demand elasticities is essential to support and mitigate policy decision making under risk conditions, concerning investments in water supply systems; investments in the water distribution and irrigation systems; efficient allocation of water with competing sectors; setting water pricing and tariffs; setting cost recovery mechanisms, and the risks encountered under lack of mitigated policy decision making.

Originality/value – This is one of few studies that addresses in detail using a parametric LP model the issue of water scarcity, related risks and subsequent impact on society in Jordan. It is expected to help policy and decision makers better formulate future estimates and demand which subsequently reduce related risks.

Keywords Risk, Risk management, Environmental management, Optimization model, Elasticities, Water demand

Paper type Research paper

1. Introduction

Water scarcity is the risk of insufficient availability of water resources needed to meet water demands. It affects every continent and around 2.8 billion people around the world are, at least, one month out of water every year. More than 1.2 billion people lack access to clean drinking water (Lester, 2011). Water scarcity involves water stress, water shortage or deficits and water crises. While the concept of water stress is relatively new, it represents the difficulty of obtaining fresh water sources for use during specific periods of time and may result in further depletion of available water resources (Chenoweth, 2008). Water shortages may be caused by climate changes, such as altered weather patterns including droughts or floods, increased pollution and increased human demand and overuse. A water crisis is a situation where the available potable and unpolluted water in a

Management of Environmental Quality: An International Journal
Vol. 29 No. 1, 2018
pp. 148-164
© Emerald Publishing Limited
1477-7835
DOI 10.1108/MEQ-10-2016-0080

specific region is less than the water demand of the same region. Water scarcity is being driven by two converging phenomena: growing fresh water use and depletion of usable fresh water resources.

Jordan is an arid to semi-arid country located to the east of the Jordan River with limited water resources (Abdel Khaleq and Dziegielewski, 2006). The country also features turbulent, and sometimes unprecedented, levels of rainfall every year (Sawalha, 2014). Jordan's topographic features vary. A mountainous range runs from the north to the south. To the east of the mountain line, ground slopes gently to form the eastern deserts, to the west ground slopes steeply toward the Jordan Rift Valley (JRV). JRV extends from Lake Tiberias in the north, at ground elevation of −220 m, to the Red Sea at Aqaba. At 120 km south of Lake Tiberias lies the Dead Sea with water level of −405 m (Ministry of Water and Irrigation (MWI), 1999/2012).

Jordan's population is growing rapidly at a growth rate of about 2.3 percent during 1999 and 2012 (Department of Statistics (DOS), 1999-2012b); the 9th highest in the world. In 1999, the population was approximately 4.7 million, and currently it is approximately 8 million as of January 2016 (Country Meters, 2016). The settlement pattern is heavily influenced by water availability. About 91 percent of the total population lives in the north – western part of the country, with 52 percent living in Amman and Zarqa area. One of the most important shared surface water resources is the Jordan River system. Other important shared water resources include the ground water resources of north Jordan (Azraq, Yarmouk and Amman Zarqa basins).

1.1 Contribution

This paper aims to: estimate the water demand elasticities using a parametric linear programming (LP) model to insight an accurate and flexible pricing policy of irrigation water in the Jordan Valley; and investigate key risk factors, related to water demand, which are likely to impact the community and other involved parties. The contribution made by this paper also includes an investigation of potential risks in irrigation water demand management by indicating the changing of water demand elasticity during growing seasons. Previous studies estimated a ridge point elasticity of demand. From a practical perspective, this research indicates that elasticity of demand is not constant in the whole growing season. It also suggests that water price polices should be made using price discrimination approaches by setting different prices of irrigation water according to growing season, water scarcity and drought conditions in order to control water demand, as well as the use of price mechanisms to conserve water.

Several studies that dealt with the pricing of irrigation and used the demand elasticity approach as a tool have estimated the water demand elasticities at annual level without considering the seasonal and monthly variation effects (Salman *et al.*, 2001; Salman and Al-Karablieh, 2004). In this research, annual and monthly water demand elasticities will be estimated to attain the decision maker to be more precise, accurate and flexible in the pricing policy of irrigation water in the Jordan Valley. The objectives of the study were to produce a set of estimates of water demand elasticities of irrigation water. Therefore, insight into the value of water demand elasticities is essential to support and mitigate policy decision making under risk conditions, regarding investments in water supply system; investments in the water distribution system and the irrigation system; efficient allocation of water with competing sectors; setting water pricing and tariffs; setting cost recovery (operation and maintenance (O&M) and capital recovery) mechanisms (Al-Karablieh *et al.*, 2012); and the risks encountered under lack of mitigated policy decision making.

The importance of this research is that it is conducted in a time when Jordan was witnessing dramatic pressures at multiple levels: political, economic, socio-cultural and environmental (Sawalha, 2017). Deteriorating global security, refugee crises in addition to

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

increasing population and the rapid expansion of municipalities and booming industries are only few examples illustrating some of the current changes taking place in Jordan, which all together, would very likely be accompanied with the need for extra massive water resources and supplies in order to accommodate the human needs for healthy survival and well-being, as well as the ability of the country to support agricultural and industrial requirements. These conditions also mandate the need for anticipating water demand elasticities and potential associated risks.

2. Literature review

2.1 The Jordan Valley

The Jordan Valley is approximately 105 km in length and encompasses 41 identifiable towns and villages. The population was approximately 161,411 in 1994 and is expected to grow for more than 295,000 by 2020 (DOS, 1999-2012b). Jordan Valley is Jordan's most fertile and productive agricultural area. Winter temperatures in the valley show an average of 15-22°C between November and March, but rise to more than 40°C in Summer. The average rainfall is 380 mm in the north, but less than 100 mm per year in the south. Consequently, production of food and other agricultural commodities is hardly possible without irrigation, posing shortage risk of such supplies (MWI, 1999/2012).

The Jordan Valley covers about 350 km^2 (equivalent to 350,000 dunums, the unit area used in Jordan) of potentially irrigable land, offering best prospects for irrigated farming especially for Winter crops produced at least two to three months prior to other parts of Middle East (Ministry of Agriculture, 1999/2012). The area is rich in agricultural lands and supplies the rest of Jordan with various products, where the planted area with vegetables is approximately 127 km^2 and the area cultivated with fruit trees is approximately 82 km^2. Meanwhile, this area depends mainly on irrigation from different sources for agricultural production. The Water Authority of Jordan has also recognized the need to implement a wastewater collection treatment facility for the agricultural communities lying along the Eastern side of the Jordan Valley between the Dead Sea and Lake Tiberius in order to contribute to the mitigation of the shortage risk (Abu-Sharar *et al.*, 2012; Alkhaddar *et al.*, 2005).

2.2 Water resources and related risks

The water shortages facing Jordan are profound and, while the country continues to undertake extensive reforms and investments into the water sector, forecasts indicate that a significant shortfall will continue to exist (Alkhaddar *et al.*, 2005). In 2013, the fresh water quantity available per capita in Jordan was about 160 m^3 per year. This is less than one-seventh of the recognized "water poverty line" of 1,000 m^3 per capita per year. This requires that water supplies and usage be managed efficiently.

Surface water supplies contribute to 32 percent of Jordan's total supply. Developed surface water was about 288 MCM in 2010 (Table I) and is expected to rise to no more than 365 MCM by 2022. Ground water contributes about 57 percent to total water supply. However, the unsustainable abstraction of ground water due to population growth, agriculture expansion and declining recharge is a major problem today that is posing a severe risk. This has been worsened by poor enforcement of regulations on private well drilling and the near absence of controls on licensed abstraction rates. As water tables drop, pumping costs and salinity levels increase. In total, 14 major populated areas (62 percent of the population) are served by sewerage systems producing about 100 m^3 of effluent per year. Most of that treated wastewater is re-used in the Jordan Valley for agriculture.

In view of the increasing population and the social and economic development of the country, the increasing volume of treated wastewater is likely to play an ever more important role in the future. It is estimated that by 2022, the volume of treated wastewater

Source	Domestic	Industrial	Irrigation	Livestock	Total	Share (%)
Surface	120.0	6.6	154.5	7.0	288.1	31.9
Ground	231.7	33.9	245.0	0.3	510.9	56.6
Treated WW	0.0	1.5	101.5	0.0	103.0	11.4
Total used	351.7	42.0	501.0	7.3	902.0	100.0
Share (%)	39.0	4.7	55.5	0.8		
			Totals without treated wastewater			
Total used	351.7	42.0	501.0	7.3	902.0	
Less treated WW	0.0	1.5	101.5	0.0	103.0	
Total net	351.7	40.5	399.5	7.3	799.0	
Share (%)	44.0	5.1	50.0	0.9		

Source: Ministry of Water and Irrigation (MWI) (1999/2012)

Table I. National water supply and consumption (MCM) by sector in 2010

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

available for reuse is 250 MCM. Irrigation uses just over half of the current available supply, around 500 MCM, though these figures may underestimate both irrigation use and total water use for various reasons. Domestic use ranks 2nd, using around 352 MCM (Al-Omari *et al.*, 2014), while industrial use is currently around 42 MCM, less than 5 percent of total supply, but is expected to grow. The MWI (1999/2012) strategy update envisions holding agricultural water use at 500 MCM into the future, and so a strong challenge will be to generate a great deal more value from the use of that amount of water.

Overdrawing of ground water aquifers creates serious negative impacts to the environment, increases water costs and lowers the water quality (Ministry of Water and Irrigation (MWI), 2010). Depletion of non-renewable water resources due to over pumping from exploited aquifers is also posing many risks. Subsequently, degradation of water quality due to increasing salinity is a fact in Jordan. Moreover, the high population growth rate (approximately 2.2 percent) (DOS, 1999-2012a) is considered a major parameter influencing future water demand. Expanding population and the climatic and topographical conditions of the country have exerted enormous pressures on water resources and created a severe water supply-demand imbalance. The supply-demand imbalance intern has influenced the quality of water resources where over abstraction from ground water aquifers exploited the aquifers at more than double their sustainable yield in the average (World Bank, 2010).

Water resources in Jordan are also facing continuous pressures from growing industrial, agricultural and municipal demand, which is expected to double by 2020. The total water use in Jordan in less than 20 years has increased by almost 60 percent. Mostly, all of Jordan's available renewable water has been developed. It is also expected that 70 percent of the projected municipal demand will occur in the urban centers of Greater Amman, Zarqa and Irbid (MWI, 2010). Risk analysis indicates that the agriculture sector is considered small compared to the overall production, but with relative importance in the production of tradable goods, as well as its importance in the socio-political structure of the country. The priority for Jordan, however, is for potable water first, then for industry and finally for agricultural demand. Water is now being diverted from agriculture in Jordan Valley into more municipal and industrial uses (Table II).

The negative water balance is partially covered by excessive unsustainable abstraction from ground aquifers, which is causing continuous drop in water levels in several aquifers. Options for augmenting water supply are limited, and the development costs are drastically increasing. The water sector in Jordan is also facing problems in management, obsolete networks of water distribution and inefficient maintenance (Al-Karablieh *et al.*, 2011). Furthermore, the control and regulation of ground water extraction of private wells is not adequate. There is no regular data

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

provided on the exact amount of water abstracted from these wells. Hundreds of farmers and individuals have illegally drilled wells without licensing (Salman, Al-Karablieh, Hans-Jochen, Heinz-Peter and Haddadin, 2008). Water prices are very low, especially relative to agricultural water value; farmers pay a water price of just \$0.017/m^3, while in the highlands pumping costs run around \$0.35/m^3, with effectively no resource fee charged. This price does not encourage water saving and provides no incentive for efficient water allocation in the Jordan Valley. It generates inadequate funding for operations and maintenance in the Jordan Valley.

Despite that the role of price in optimizing the use of water resources is conceived as a mitigant, charging for water use has never been fully applied. Prevailing water tariffs and charges, despite their recent increase, are set at levels that barely cover O&M cost of domestic, wastewater and fall short of covering the O&M cost of irrigation water. Accordingly, incentives for water saving and conservation practices are almost absent.

In a country facing such risks and imbalance between limited supplies and ever-growing demand, the government has to be able to deal with difficult policy decisions and trade-offs in order to determine the best ways in which to allocate water across sectors. Also, the interest in wastewater treatment has to increase in Jordan as a reliable source of water due to population growth and mitigation of environmental problems caused by the flow of wastewater (Wolff, Wolf, Subah, Guttman, Tamimi, Jarrar, Salman and Karablieh, 2012). Wastewater shall not be treated as waste. It shall be collected and treated in accordance with WHO and FAO guidelines that allow its reuse in unrestricted agriculture and other non-domestic purposes, including ground water recharge.

2.3 A review of recent studies

A parametric LP model is used for the purpose of this research. LP proved to be an effective approach and therefore was used in similar studies in various geographical contexts (Graveline, 2016). For instance, Li and Guo (2014) developed a model to be applied to irrigation water resources optimal allocation system in Minqin's irrigation areas in China. Li, Guo and Singh (2016) have also developed an interval linear fractional irrigation water allocation model in response to the complexity of errors in estimating crop yields, fluctuating hydrological elements, as well as varying economic profits in an irrigation system. The model reflects the uncertainties of the variables and functions involved in northwest China. Davijani *et al.* (2016) used a model that applies the particle swarm optimization algorithm in order to determine the optimum amount of water allocated to each water-demanding sector, area under cultivation, agricultural production, employment in the agriculture sector, industrial production and employment in the industry sector in the central desert region of Iran.

Hu *et al.* (2016) developed a multi-objective model involving water allocation equality and economic efficiency risk control to help water managers mitigate potential problems and allowing relevant authorities to determine water allocation strategies for a single river basin, the "Qujiang" in China. Filippi *et al.* (2017) developed two mixed integer LP models for optimal crop selection problem. The first model suggests an aggressive strategy, where the

Sector	Water demand (including physical losses) (MCM (%)) 2005	2010	2015	2020
Municipal and tourist	372 (24)	415 (27)	460 (29)	513 (32)
Industry	59 (4)	77 (5)	100 (6)	120 (7)
Agriculture	1,102 (72)	1,072 (69)	1,040 (65)	983 (61)
Total	1,534 (100)	1,564 (100)	1,600 (100)	1,616 (100)

Source: Ministry of Water and Irrigation (MWI) (2010)

Table II.
Projected annual water demand per sector including physical losses

expected total profit is maximized. The second takes into consideration the variability in prices and yields by incorporating the conditional value-at-risk as a safety measure. Li, Guo, Singh and Yang (2016) developed a framework for allocation of agricultural land-water resources and risk evaluation under uncertainty. The framework is applied for optimization of agricultural water and land resources in the middle reaches of "Heihe" River basin in China. Fang *et al.* (2015) investigated the economic impacts of intra- and inter-regional water reallocation on sectoral transformation and economic growth. Others, such as Veintimilla-Reyes *et al.* (2016) considered the water allocation problem as a network flow optimization problem that can possibly be solved by a spatio-temporal optimization approach using mixed integer LP techniques.

3. Methodology

The research relies on secondary data that have already been collected during the period 2010/2011 and updated according to the input and output prices for the year 2010/2011. Data include: the gross margins for all crops by season (Winter and Summer), water supply quantities which were obtained from the Jordan Valley Authority (JVA) – Ministry of Water and Irrigation (MWI) for the last five years (2008/2009-2012/2013) (note that cultivation and irrigation in the Jordan Valley starts on October of a specific year (i.e. October, 2010) and ends by the end of September of the next year (i.e. September, 2011)), in addition to the cultivated crop areas in the study area which have been obtained from the Department of Statistics for the last eight years (2006-2013) and to the farm-gate prices for the last four years (2010-2013) in order to avoid or minimize any possible deviations that could happen to the input data of the LP model.

3.1 LP model

A parametric LP model is used to maximize the total net income of the investigated area. The model generates cropping patterns that maximize net agricultural income at the regional level. A historical cropping pattern for all crops planted in the area of the study was used as constraints and was formulated in a way to avoid the exaggerated expansion of planted crops especially fruit trees and banana which are highly consumptive of irrigation water. Moreover, the objective function was subjected to water constraints formulated on monthly basis, and water storage-transfer activities were added to water constraints to get the optimal water scheduling that maximizes the net revenue (Salman *et al.*, 2001). Constraints to the model included: the available land, the gross water requirements of all crops planted in the Middle and Southern Jordan Valley, water supply quantities, fertilizers and labor constraints for the different crops per hectare and cropping patterns as an average for several years (2000-2007) and the gross margins of crops that had been calculated.

The model was applied on different seasons to assess the impact of the use of blended treated wastewater on the economics on the study area (Doppler *et al.*, 2002; Salman and Al-Karablieh, 2004; Al-Karablieh and Salman, 2004). Thus, time series of monthly water supply date under different scenarios to derive the annual and monthly water demand elasticities for the blended treated wastewater in the study area. It is worthwhile mentioning that other factors have been assessed, such as crops yields; total net income; water allocation; and labor and fertilizers. The mathematical notation of the LP model is as follows (note: 1 dunum = 0.001 km^2 and 1JD = \$1.41):

$$\text{Max } Z = \sum_{j=i}^{n} \sum_{m=i}^{n} X_{jm} \left[WRC_{jm} - \sum_{i} \sum_{m} (P_{im} W_{im}) \right] \quad (1)$$

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

where Z represents the maximum achieved total net agricultural income in MJD; WRC_{jm} the water-related constraint of activity j using water during season m in cubic meter (CM); W_{im} the water supply in month i at season m; P_{im} the price of water during month I in JD/CM. At season m, X_{jm} the total land area of activity j produced in season m in dunum (Winter and Summer). The objective function is subjected to the following constraints.

3.2 Water constraints

The first step has been carried out to determine the gross water requirements for the different crops planted in the Middle and Southern Jordan Valley, as estimated by the MWI. The model has been formulated to contain a 12-month irrigation scheme consequently, helping the user in choosing different planting seasons and allowing water to vary according to any required rationing of water resources. As for the second step, it targeted the supply and the storage-transfer constraints. These constraints were formulated in a way that current inflow can be used in present irrigation, or can be stored to be used in the coming season:

$$\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n} a_{ijm}X_{jm} + \sum_{i=1}^{n}\left(-w_i^0 - w_{i-1}^{+} + w_{i+1}^{-}\right) \leq 0 \tag{2}$$

where a_{ijm} is the water requirement of activity j (cucumber, tomato, etc.), at month i (October to September) in season m (Winter or Summer) in m^3/dunum; W_i^0 the total supply of water of month i, excluding storage in CM; W_{i-1}^{+} the transfer of water from the month before i; and W_{i+1}^{-} the transfer of water to the month after I in CM.

3.3 Land constraints

The second constraint involves the land area. Land area can be specified in accordance with crop groups (fruit trees, vegetables or field crops), and the cropping season (Winter or Summer):

$$\sum_{j=1}^{n}\sum_{m=1}^{n}\sum_{k=1}^{n} X_{jmk} \leq A_{mk} \tag{3}$$

where X_{jm} the total land area of activity j produced in season m of crop category k (Winter or Summer) in dunums; and A_{mk} the total allocated area in dunums in season m for crop group k, where the crop groups are field crops, vegetables or fruit trees.

3.4 Fertilizer constraints

Two kinds of fertilizers have been used and they are: chemical fertilizers which include trace elements and compound fertilizers, and the second kind is the organic fertilizer:

$$\sum_{j}\sum_{e}\sum_{m} F_{jem}X_{jm} \geqslant 0 \tag{4}$$

where X_{jm} is the total land area of activity j produced in season m (Winter or Summer) in dunums; and F_{jem} the fertilizer requirements from fertilizer e (organic and chemical fertilizers) for activity j in season m in kg/dunum.

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

3.5 Labor constraints

The two kinds of labor in the analysis are: hired and family labor:

$$\sum_{j}\sum_{v}\sum_{m} L_{jvm}X_{jm} \geqslant 0 \tag{5}$$

where X_{jm} is the total land area of activity j produced in season m (Winter or Summer) in dunums; and L_{jvm} the labor requirement from v (hired or family labor) for activity j in season m in h/dunum.

In addition, regression analysis was used in order to derive the annual demand function, as well as the demand functions per month under different levels of water prices and quantities in order to estimate the annual and monthly elasticities for water in the study area. These functions took the log-log form, which $\log Q = \log\alpha + \varepsilon \log p$. This equation can be converted into the following form $Q = \alpha P^{\varepsilon}$, where Q is the water quantity demanded; P the price of water; α the intercept; and ε is the demand price elasticity.

4. Findings and discussion

Due to the favorable climatic conditions in the Jordan Valley, a large number of crops can be grown successfully. These crops include almost all types of vegetables in Summer and Autumn, such as subtropical trees (e.g. citrus, grapes, date palms and others), a number of tropical trees (e.g. banana, mango, avocado and guava), certain varieties of temperate climate trees (e.g. apple and peaches) and temperate climate cereals (e.g. wheat and barley) in Winter and more (Jabarin and Al-Karablieh, 2011).

4.1 Cropping patterns under declined levels of water supply

In this research, three cases were presented; existing supply, reduction by 20 percent and 40 percent. When decreasing the prevailing water supply (104 MCM) by 20 percent and 40 percent, the fruit tree area decreased by 19.7 percent and 38 percent from 26.7 km^2 to 21.434 km^2 and 16.521 km^2, respectively. In the case of vegetables, two seasons of crop production exist in the Valley; Autumn, during which crops are planted between September and November, and Spring (Table III). In the Jordan Valley, there are five main vegetable types that are often planted by farmers during Autumn and Spring. These crops include tomatoes, squash, eggplant, cucumber and potato.

The main reasons behind the increase of production of vegetables were the adoption of plastic houses, new irrigation technologies, high yielding varieties and the adoption of chemical fertilizers and pesticides. The area of the prevailing cropping pattern under the current water supply and water price is as follows: tomato under plastic houses constituting 15.8 percent of the total vegetable area was 49.915 km^2 (Table III), the total Autumn vegetable area of the total planted area was decreased to 46.396 km^2 (7 percent) and 44.587 km^2 (10.7 percent) when decreasing the water supply by 20 percent and 40 percent. In the case of Spring grown vegetables the prevailing cropping pattern under the existing water supply was as follows: tomato grown under plastic houses constituting 22.6 percent of the total Spring vegetable area, followed by squash, eggplant and potato each constituting 16.5 percent, 14 percent and 7.7 percent of the total Spring area, respectively (Table III). In the case of water reduction by 20 percent and 40 percent, the total Spring vegetable area reduced by 1.5 percent and 54.9 percent from 29.120 to 28.691 km^2 and 13.128 km^2, respectively.

The drop in both seasons, Autumn and Spring, was caused by the decrease of the open field area, as the area of plastic houses and tunnels was not affected by the decrease, except for the case of vegetables grown in Spring under plastic houses they dropped significantly by 56.6 percent from 11.646 km^2 to 5.054 km^2 due to the exclusion of various crops, such as tomatoes, which is considered as a low yielding crop compared to others (Table III).

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Indicators	Unit	Existing supply 104 (MCM)	20% decrease	40% decrease
Total net income	Mil JD	36.064	34.276	29.602
Total net income	Mil JD	36.064	34.276	29.602
Total income	Mil JD	37.629	35.528	30.541
Total area in the Jordan Valley	du	121,470	97,414	74,236
Area of vegetables in open field during Autumn season	du	30,735	27,216	25,407
Area of vegetables under plastic tunnels during Autumn season	du	7,574	7,574	7,574
Area of vegetables under plastic houses during Autumn season	du	11,606	11,606	11,606
Total area of vegetables grown during Autumn season	du	49,915	46,396	44,587
Area of vegetables in open fields during Spring season	du	11,633	11,205	2,234
Area of vegetables under plastic houses during Spring season	du	5,841	5,841	5,841
Area of vegetables under plastic houses during Spring season	du	11,646	11,646	5,054
Total area of vegetables grown during Spring season	du	29,120	28,691	13,128
Fruits area	du	26,700	21,433	16,521
Field crops area	du	15,735	893	0

Source: Estimates of LP model

Table III.
The changes in income and the areas planted under the different water supply (1 dunum (du) = 0.1 hectare) in MCM

The major field crops grown in that area are barley and wheat. In the case of 20 percent and 40 percent decrease in the water supply, the total field crop area reduced significantly to 0.893 km^2 and 0 km^2, respectively, thus it can be argued that water is being allocated to more profitable crops, such as fruits and vegetables. As for the farmers' income, under the prevailing water supply the income was M$52.8, and it decreased by 5.58 percent and 18.84 percent under scenarios when there was 20 percent and 40 percent decrease in the water supply, respectively.

The net income without optimization was M$49.4. After optimization of water allocation, the net income increased to M$50.8 equivalent to an increase of 4.65 percent. As shown in Table III, the total net income of the existing water supply of 104 MCM is M$50.6. Decreasing water supply by 20 percent led to a decrease of total income to M$48.11, which represents 4.95 percent. Decreasing water supply by 40 percent led to a reduction in the total net income with 17.91 percent (equivalent to M$41.5).

4.2 Cropping pattern under different levels of water prices

Table IV shows the different cropping patterns for fruit trees under different prices. The effect of prices of water can be observed on the prevailing cropping pattern of fruit in

	Price (JD/CM)							
Crop	0.005	0.015	0.040	0.09	0.1525	0.165	0.365	0.39
Banana	10,425	10,425	10,424	10,424	10,424	10,424	0	0
Clementine	2,481	2,481	2,481	0	0	0	0	0
Grapes	3,133	3,133	3,132	3,132	3,132	0	0	0
Lemon	1,727	1,727	1,727	1,727	1,727	1,727	1,727	0
Mandarin	1,578	1,578	1,578	1,578	0	0	0	0
Olive	1,207	1,207	0	0	0	0	0	0
Orange	3,591	3,591	3,590	3,590	3,590	3,590	0	0
Other	2,558	2,558	2,558	2,558	2,558	2,558	2,558	2,558

Source: Calculated by LP model

Table IV.
The effect of changing water prices in JD/CM on the area planted of fruit trees in dunums

the study area, when the price of water irrigation started from \$0.007/CM, more land was used hence more crops were produced. As prices increased gradually more crops left the solution, for example, olive left at \$0.06/CM and Clementine was left at \$0.12/CM, and as it can be seen, as the prices of water increase, the cropping pattern of the fruit trees changes and fewer trees are planted. With the increase in water prices, the field crop area is decreased (Table V). This can be explained by allocating water to more profitable crops, such as fruit trees or vegetables and the returns of those crops are low in a way that cannot cover the increased expenses of water.

In the case of vegetables, Tables V and VI represent the cropping pattern under different prices of water and during different seasons, as was also been mentioned by Salman, AL-Karablieh and Haddadin (2008). Tables VI and VII show the cropping pattern of vegetables grown in Autumn and Spring using different production systems. Furthermore, they show "what if" scenarios: of what is likely to happen to the cropping pattern if water price increases by a certain amount. Most crops will be produced under plastic tunnels and houses to reduce water losses and to insure high production and subsequently the income. Moreover, crops planted during Autumn seasons are more resistible to water price increases than those planted during Spring due to mainly two reasons: first, water during Winter is more available and second, product prices during Autumn are at their peak as the production of crops is lower compared to those during Spring due to lower temperatures during Autumn seasons.

4.3 Demand functions of water

Demand functions and elasticities are derived to estimate the willingness to pay in case of changing water supply and during different months. Demand price elasticities of water are used to draw general pricing policies to control water demand and to use it more efficiently.

	Price (JD/CM)							
Crop	0.010	0.015	0.040	0.0775	0.1025	0.115	0.1275	0.14
Barley	8,486	8,486	8,485	8,485	8,485	8,485	8,485	0
Wheat	7,020	7,020	7,019	7,019	7,019	0	0	0
Other	230	230	229	0	0	0	0	0

Source: Estimates of LP model

Table V. The effect of changing water prices in JD/CM on the area planted of field crops in dunums

		Price (JD/CM)						
Crop	Technology	0.005	0.015	0.14	0.2775	0.54	0.865	1.015
Broad bean	Open field	3,474	3,474	3,474	3,474	3,474	0	0
Cauliflower	Open field	1,145	1,145	1,145	1,145	1,145	0	0
Onion green	Open field	1,734	1,734	1,734	1,734	1,734	0	0
String beans	Open field	2,074	2,074	2,074	2,074	2,074	2,074	0
Sweet pepper	Open field	1,165	1,165	1,164	1,164	1,164	0	0
Potato	Open field	9,752	9,752	9,752	9,751	9,752	0	0
Eggplant	Open field	6,065	6,065	6,064	6,064	6,064	6,064	0
Squash	Plastic tunnel	7,574	7,574	7,574	7,574	7,574	0	0
Cucumber	Plastic house	3,737	3,737	3,737	3,737	3,737	3,737	3,737
Tomato	Plastic house	7,869	7,869	7,869	7,869	7,869	7,869	0
Other	Open field	3,519	3,519	0	0	0	0	0

Source: Estimates of LP model

Table VI. The effect of changing water prices in JD/CM on the area planted by vegetables during Autumn season in dunums

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Table VII.
The effect of changing water prices in JD/CM on the area planted by vegetables during Spring season in dunums

Crop	Technology	Price (JD/CM) 0.005	0.015	0.09	0.14	0.2025	0.565	0.715
Jew's mellow	Open field	1,809	1,809	1,809	1,809	1,809	0	0
Cabbage	Open field	429	429	0	429	0	0	0
Squash	Plastic tunnel	4,791	4,791	4,791	4,791	4,791	0	0
String beans	Plastic tunnel	1,050	1,050	1,050	1,050	1,050	0	0
Potato	Open field	2,234	2,234	2,234	2,234	2,234	0	0
Sweet pepper	Plastic house	371	371	371	371	371	0	0
Eggplant	Plastic house	4,110	4,110	4,110	4,110	4,110	4,110	4,110
Onion Dry	Open field	829	829	829	829	0	0	0
Cauliflower	Open field	259	259	259	259	259	0	0
Tomato	Plastic house	6,592	6,592	6,592	6,592	6,592	0	0
Cucumber	Plastic house	573	573	573	573	573	573	0
Other	Open field	7,883	7,883	7,882.5	7,883	0	0	0

Source: Estimates of LP model

Many factors influence the values of water price elasticity including: sector, season and region (developed vs developing and rural vs urban). The available evidence shows that the elasticity of water demand in terms of water prices is relatively low and inelastic, particularly in the agricultural sector.

Low water prices and poor cost recovery compromise the efficient maintenance of existing water infrastructure, as well as the additional investments necessary to develop future water projects. Even more fundamentally, low water prices encourage misallocation and wasteful water use within almost all sectors. If higher water prices could substantially reduce the withdrawal of water in other sectors, the savings would be available for environmental uses and others. Despite the potential benefits of higher water prices, policymakers found it difficult to raise them, especially in the agricultural sector, because of concerns over impacts on food production and farmer and poor household incomes (Wolff, Al-Karablieh, Al-Assa'd, Subah and Salman, 2012).

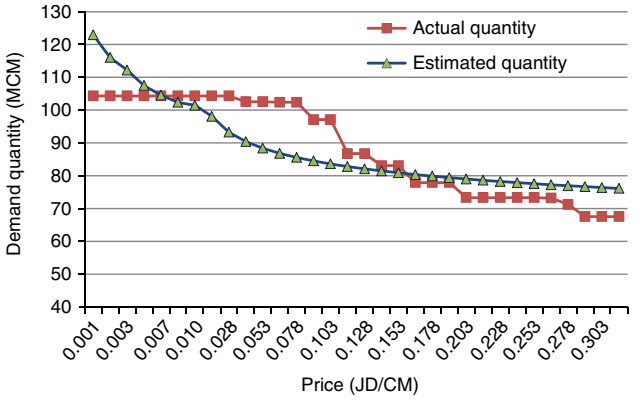
In this paper, the demand function of water was estimated by performing several runs at different water prices to determine the quantity demanded by farmers at different water prices. This was followed by estimating the logarithm of both water quantity and the price and regressing the quantity of water as a dependent variable on the price of water as an independent variable and finally using regression analysis to derive elasticity of demand.

Table VIII and Figure 1 show the demand functions and the elasticity of water demand. Under different regimes of water supply, where the elasticity of water demand decreases as the water supply decreases, farmers would give up less water at different levels of water prices when the available water supply decreases. In case of the decrease in water supply by 20 percent and 40 percent, it can be seen that if the waster price increased by 100 percent the farmer will use less water 16.1 percent and 11.2 percent, respectively. This reflects the low income that will be generated by the reduction of water, hence the farmer would not be able

Table VIII.
Demand functions under different water supply

Different cases	Demand function	R^2	$t_{\beta 1}$-value	F	Price elasticity
Existing supply	$Q = 7.60\ P^{-0.215}$	0.42	(−5.21)*	27.13**	−0.215
Decreasing 20%	$Q = 7.62\ P^{-0.161}$	0.28	(−3.93)*	15.44**	−0.161
Decreasing 40%	$Q = 7.59\ P^{-0.112}$	0.21	(−3.24)*	10.51**	−0.112

Notes: Parentheses are t-values. *,**Significant at $\alpha = 0.01$ and $\alpha = 0.05$, respectively



Note: JD1=$1.4 as per January 2017
Source: Estimates of LP model

Figure 1.
Actual annual water demand function in the Jordan Valley

to compensate for the additional cost of water, but at the same time, it reflects farmers' willingness to pay higher prices for water as long as the income covers the cost.

Table IX represents the monthly water demand functions and their elasticity, the demand functions were estimated at a significant level of 1 percent, and the demand elasticities were derived from the demand function where the elasticities reflect the percentage change in quantities due to a percentage change in water prices.

As for the demand of water per month under different water prices, Table VIII shows the demand function of different months. From Table IX, it can be noticed that the demand elasticity is high (excluding the sign) for those in Spring and Summer than those for Fall and Winter; meaning that during Spring and Summer farmers are willing to forgo larger amounts of water than in other months. This is because the amount of area planted during Spring season is much less than that of Autumn and Winter. Thus, farmers will not be using large amounts of water and will not mind giving it up. This can be explained by the regulations that are carried out by JVA to save water during Spring and Summer seasons, such as preventing Spring and Summer plantation. Furthermore, it points out that Autumn is the main production season. As for the demand function of different months, Figures 2 and 3 show the

Different cases	Demand function	R^2	$t_{\beta 1}$-value	F-test	Price elasticity
Total	$Q = 7.60\ P^{-0.215}$	0.42	(−5.21)*	27.13	−0.215
September	$Q = 6.57\ P^{-0.168}$	0.39	(−4.89)*	23.95	−0.168
October	$Q = 6.73\ P^{-0.126}$	0.36	(−4.61)*	21.23	−0.126
November	$Q = 6.69\ P^{-0.116}$	0.48	(−5.86)*	34.32	−0.116
December	$Q = 6.41\ P^{-0.133}$	0.43	(−5.32)*	28.29	−0.133
January	$Q = 6.11\ P^{-0.228}$	0.4	(−5.04)*	25.39	−0.228
February	$Q = 6.10\ P^{-0.254}$	0.52	(−6.36)*	40.46	−0.254
March	$Q = 6.32\ P^{-0.269}$	0.52	(−6.38)*	40.67	−0.269
April	$Q = 6.60\ P^{-0.276}$	0.48	(−5.96)*	35.55	−0.276
May	$Q = 6.61\ P^{-0.280}$	0.37	(−4.73)*	22.33	−0.28
June	$Q = 6.58\ P^{-0.270}$	0.36	(−4.61)*	21.26	−0.27
July	$Q = 6.41\ P^{-0.300}$	0.32	(−4.19)*	17.57	−0.3
August	$Q = 6.48\ P^{-0.255}$	0.34	(−4.45)*	19.84	−0.255

Notes: Figures between parentheses are t-values. *,**Significant at $\alpha = 0.01$ and $\alpha = 0.05$, respectively

Table IX.
The water demand functions of the different months

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

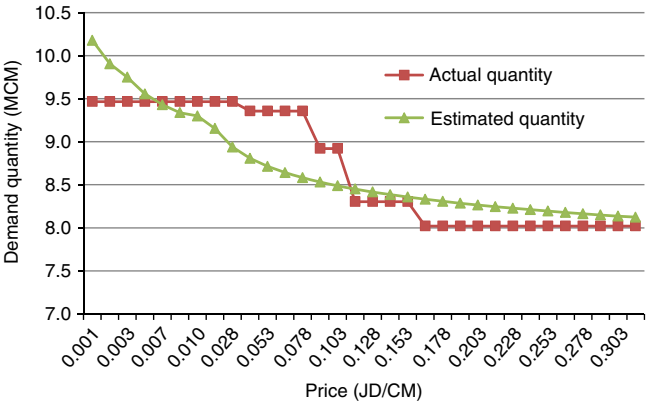


Figure 2.
Water demand function for October

Source: Estimates of LP model

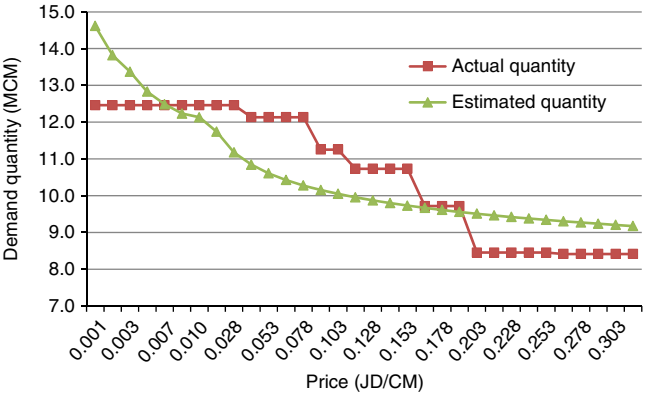


Figure 3.
Water demand function during June

Source: Estimates of LP model

estimated quantity and the actual amount supplied in October as an example on water demand during Autumn, and June as an example for Spring.

Finally, to show the advantages of adopting optimization, a comparison between the current water allocation status and results of the LP model was made. Table X shows that the impact of optimization of the allocated irrigation water in the study areas has led to a remarkable increase in the amount of water quantities used during dry months, namely, months between April and October, where the model has reallocated water quantities and stored them in dams starting from November until March and re-used these quantities again during high peak water demand season.

4.3.1 Water demand elasticity in sub-seasons. All estimates of price elasticities based on this approach have found the demand for irrigation water to be very inelastic at low prices. This result is consistent with the international findings. Zekri *et al.* (2006) found that price elasticity of irrigation water demand in water markets in Oman to range from −0.10 to −0.28. The estimates of short-run water demand elasticity in Australia range from −0.02 to −2.81 (Pagan *et al.*, 1997). The price elasticities of bid demand by month ranged from −0.116 to −0.30, while the overall price elasticity of demand is −0.215. The lowest price elasticity is

	Actual monthly water quantity (MCM)	Optimal monthly water quantity (MCM)	Reallocated amount of water (MCM)	Increase/ Decrease (%)
October	6.121	9.466	3.345	54.6
November	11.481	8.409	−3.072	−26.8
December	12.437	4.697	−7.740	−62.2
January	13.529	3.555	−9.974	−73.7
February	9.640	4.012	−5.628	−58.4
March	7.670	7.124	−0.546	−7.1
April	6.966	13.904	6.938	99.6
May	6.970	13.797	6.827	97.9
June	7.444	12.461	5.017	67.4
July	8.829	9.614	0.785	8.9
August	7.147	9.365	2.218	31.0
September	6.105	7.937	1.833	30.0
Total	104.341	104.341		

Table X.
Optimal monthly water allocation and actual supply in the study area

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

in November with −0.116. The results in general indicate that the irrigators are not responsive to increasing price of water as water costs represent a neglected portion of total production costs.

4.3.2 Key significant and conclusive results. Water is relatively expensive in Jordan because of the scarcity and the high cost involved in acquiring, treatment, transporting and distribution. The actual costs of delivering water to consumers are estimated at \$1.14/m^3 for municipal purposes and \$0.32/m^3 for irrigation in the Jordan Valley. The Government of Jordan has been subsidizing these services. Water in the Jordan Valley is charged according to the principle of price discrimination. The block water rates structure is divided into four steps depending on the level of water usage. The farmer's payment depends on the total water consumption. It ranges from \$0.0114/m^3 to \$0.05/m^3 with an average of \$0.027/m^3 (Al-Karablieh *et al.*, 2012). The average price of irrigation water sold to farmers in the Jordan Valley is just JD0.017/m^3, while the average value of water used in the Jordan Valley to produce crops is more than 50 times that value (US\$0.89/m^3). The average value of water used to produce Winter vegetables in the Jordan Valley is more than 100 times the water price to farmers (Tabieh *et al.*, 2015).

The results indicate that irrigators' response to pricing is very low. Other policy instruments are driven by many other factors than just the financial. The cost of water represents less than 2 percent of the total production costs. Clearly, there is wide scope for increasing the price charged, which would have a number of potential positive results. The need to increase costs to conserve water is especially true in the agricultural sector where the low costs of water and electricity are encouraging the wastage of water into low-value agricultural activities and therefore are not always rational in an economic sense.

5. Conclusion

The Jordan Valley is suffering from water scarcity risk, and consequently the area to be planted is not fully utilized, leading to lower cropping intensities. Compared to field crops, vegetables and fruit trees were considered the most profitable crops in (MJV) and (SJV), due to their high production and relatively higher prices. The findings revealed that when decreasing the usual water supply, the fruit tree area decreased. Decreasing usual water supply also led to a drop in production of vegetables, both in Autumn and Spring seasons. The net income also decreased as a result of decreasing usual water supplies. Therefore, for vegetables, the most successful growing method was planting under the plastic houses

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

for most crops, in respect to their high productivities, proper use of water and planting dates which are crucial to farmers in order to obtain the highest market prices.

The results also revealed that as the prices of water increased, the cropping pattern of the fruit trees changed and fewer trees were planted. With the increase in water prices, the field crop area was also reduced. As for vegetables planted during Autumn seasons, the findings showed that these are more resistible to water price increases than those planted during spring due mainly to two reasons: first, water during Winter is more available and second, product prices during Autumn are at their peak as the production of crops is lower compared to those during Spring due to lower temperatures during Autumn seasons.

The results also showed that there are various factors that influence the values of water price elasticity including: sector, season and region (developed vs developing and rural vs urban). The available evidence shows that the elasticity of water demand in terms of water prices is relatively low and inelastic, particularly in the agricultural sector. The analysis shows that the low income that will be generated by the reduction of water, hence the farmer would not be able to compensate for the additional cost of water, but at the same time, it reflects farmers' willingness to pay higher prices for water as long as the income covers the cost.

Overall, farmers seemed to mistrust government statements and insist on farming typical crops despite the high level of risk and potential financial losses. The Southern Jordan valley is the most productive and suitable area for banana production despite its high water requirements. Reducing water supply, led to a risky increase in unemployment rate. As a result, farmers' standard and well-being will be negatively affected. It is also noticeable that hired labor is used more than family labor in the study area, and due to the lack of skilled family labor, this will lead to the increase of cost production, thus reducing the income of the farmer. Water policies can be used to put limitation on the use of water during dry months (Spring and Summer). Price elasticities for drier months (Spring and Summer) were higher than cooler months (Autumn and Winter), which indicates the enforcement of the Jordanian law that prohibits or limits Summer plantation.

In this paper, the main objective was to optimize water allocation using parametric LP. There was no specific goal regarding a certain income or production quantity since the main problem in Jordan is water scarcity which is much more important in this current research than any other problem. Goal programming can be considered for future studies in order to achieve certain goals.

To put into perspective, the findings of this paper are expected to guide decision makers in Jordan and put forward targeted some policy recommendations in order to ensure better outcomes of current ineffective frameworks and mechanisms. First, and unlike anywhere else in the region, the Jordan Valley features favorable climatic conditions which are considered as a unique resource, as well as a core competence, thus, optimization of water allocation will certainly result in increased net income to farmers. Second, the results indicate that irrigators' response to pricing is very low. Since the cost of water represents less than 2 percent of the total production costs, there is wide scope for increasing the price charged, which would have a potential positive impact on discouraging the wastage of water into low-value agricultural activities.

References

Abdel Khaleq, R. and Dziegielewski, B. (2006), "A national water demand management policy in Jordan", *Management of Environmental Quality*, Vol. 17 No. 2, pp. 216-225.

Abu-Sharar, T., Al-Karablieh, E. and Haddadin, M. (2012), "Role of virtual water in optimizing water resources management in Jordan", *Water Resources Management*, Vol. 26 No. 14, pp. 3977-3993.

Al-Karablieh, E. and Salman, A. (2004), "Measures of variation in net returns and their impact on regional cropping plans and temporal water allocation", *Dirasat-Agricultural Sciences*, Vol. 31 No. 2, pp. 195-212.

Al-Karablieh, E., Jabarin, A.S. and Tabieh, M.A. (2011), "Jordanian horticultural export competitiveness from water perspective", *Journal of Agricultural Science and Technology*, Vol. 1 No. 7B, pp. 964-974.

Al-Karablieh, E., Salman, A., Al-Omari, A., Wolff, H., Al-Assa'd, T., Hunaiti, D. and Subah, A. (2012), "Estimation of the economic value of irrigation water in Jordan", *Journal of Agricultural Science and Technology*, Vol. 5 No. B2, pp. 487-497.

Alkhaddar, R., Sheehy, W. and Al-Ansari, N. (2005), "Jordan's water resources", *Water International*, Vol. 30 No. 3, pp. 294-303.

Al-Omari, A., Salman, A. and Karablieh, E. (2014), "The red dead canal project: an adaptation option to climate change in Jordan", *Desalination and Water Treatment*, Vol. 52 No. 13, pp. 2833-2840.

Chenoweth, J. (2008), "Minimum water requirement for social and economic development", *Desalination*, Vol. 229 Nos 1-3, pp. 245-256.

Country Meters (2016), "Jordan population", available at: http://countrymeters.info/en/Jordan (accessed December 20, 2016).

Davijani, M., Banihabib, M.E., Anvar, A. and Hashemi, S.R. (2016), "Optimization model for the allocation of water resources based on the maximization of employment in the agriculture and industry sectors", *Journal of Hydrology*, Vol. 533 No. 1, pp. 430-438.

Department of Statistics (DOS) (1999-2012a), "Annual Agriculture Statistics", Department of Statistics, Amman.

Department of Statistics (DOS) (1999-2012b), "Population Statistics Division", Department of Statistics, Amman, available at: www.dos.gov.jo/dos_home_e/main/index.htm (accessed October 20, 2016).

Doppler, W., Salman, A., Al-Karablieh, E. and Wolff, H. (2002), "The impact of water price strategies on irrigation water allocation under risk: the case of Jordan Valley", *Agricultural Water Management*, Vol. 55 No. 3, pp. 171-182.

Fang, X., Roe, T. and Smith, R. (2015), "Water shortages, inter-sectoral water allocation and economic growth: the case of China", *China Agricultural Economic Review*, Vol. 7 No. 1, pp. 2-26.

Filippi, C., Mansini, R. and Stevanato, E. (2017), "Mixed integer linear programming models for optimal crop selection", *Computers and Operations Research*, Vol. 81 No. 1, pp. 26-39.

Graveline, N. (2016), "Economic calibrated models for water allocation in agricultural production: a review", *Environmental Modelling & Software*, Vol. 81 No. 1, pp. 12-25.

Hu, Z., Wei, C., Yao, L., Li, L. and Li, C. (2016), "A multi-objective optimization model with conditional value-at-risk constraints for water allocation equality", *Journal of Hydrology*, Vol. 542 No. 1, pp. 330-342.

Jabarin, A. and Al-Karablieh, E. (2011), "Estimating the fresh vegetables demand system in Jordan: a linear approximate almost ideal demand system", *Journal of Agricultural Science and Technology*, Vol. 5 No. 3, pp. 322-331.

Lester, R. (2011), "Water scarcity crossing national borders", Earth Policy Institute.

Li, M. and Guo, P. (2014), "A multi-objective optimal allocation model for irrigation water resources under multiple uncertainties", *Applied Mathematical Modelling*, Vol. 38 No. 1, pp. 4897-4911.

Li, M., Guo, P. and Singh, V. (2016), "An efficient irrigation water allocation model under uncertainty", *Agricultural Systems*, Vol. 144 No. 1, pp. 46-57.

Li, M., Guo, P., Singh, V. and Yang, G. (2016), "An uncertainty-based framework for agricultural water-land resources allocation and risk evaluation", *Agricultural Water Management*, Vol. 177 No. 1, pp. 10-23.

Ministry of Agriculture (1999/2012), "Annual reports", Ministry of Agriculture, Amman.

Ministry of Water and Irrigation (MWI) (1999/2012), Annual Reports.

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Downloaded by UNIVERSITY OF JORDAN At 07:47 03 January 2018 (PT)

Ministry of Water and Irrigation (2010), available at: www.mwi.gov.jo/sites/en-us/Best%20Managment%20Practices/water%20High%20Rise%20English.pdf (accessed November 25, 2017).

Pagan, P., Fagan, M., Crean, J. and Jones, R. (1997), "Short and long run approaches to water demand estimation", *41st Annual Conference of the Australian Agricultural and Resource Economics Society, Gold Coast, 22-24 January*.

Salman, A.Z. and Al-Karablieh, E. (2004), "Measuring the willingness of farmers to pay for groundwater in the highland areas of Jordan", *Agricultural Water Management*, Vol. 68 No. 1, pp. 61-76.

Salman, A., Al-Karablieh, E. and Fisher, F. (2001), "An inter-seasonal agriculture water allocation systems (SAWAS)", *Agricultural System*, Vol. 68 No. 1, pp. 233-252.

Salman, A., AL-Karablieh, E. and Haddadin, M. (2008), "Limits of pricing policy in curtailing household water consumption", *Water Policy*, Vol. 10 No. 3, pp. 295-307.

Salman, A., Al-Karablieh, E., Hans-Jochen, R., Heinz-Peter, W. and Haddadin, M. (2008), "Participatory irrigation water management in the Jordan Valley", *Water Policy*, Vol. 10 No. 4, pp. 305-322.

Sawalha, I. (2014), "Collaboration in crisis and emergency management: identifying the gaps in the case of Storm Alexa", *Journal of Business Continuity and Emergency Planning*, Vol. 7 No. 4, pp. 312-323.

Sawalha, I. (2017), "A context-centered, root cause analysis of contemporary terrorism", *Disaster Prevention and Management: An International Journal*, Vol. 26 No. 2, pp. 183-202.

Tabieh, M., Al-Karablieh, E.K., Salman, A., Al-Qudah, H., Al-Rimawi, A. and Qtaishat, T. (2015), "Farmers' ability to pay for irrigation water in the Jordan Valley", *Journal of Water Resource and Protection*, Vol. 7 No. 15, pp. 1157-1172.

Veintimilla-Reyes, J., Cattrysse, D., Meyer, A. and Orshoven, J. (2016), "Mixed integer linear programming (MILP) approach to deal with spatio-temporal water allocation", *Procedia Engineering*, Vol. 162 No. 1, pp. 221-229.

Wolff, H.-P., Al-Karablieh, E., Al-Assa'd, T., Subah, A. and Salman, A.Z. (2012), "Jordan water demand management study", *Water Science and Technology: Water Supply*, Vol. 12 No. 1, pp. 38-44.

Wolff, H.P., Wolf, L., Subah, A., Guttman, J., Tamimi, A., Jarrar, A., Salman, A. and Karablieh, E.K. (2012), "Methodological challenges in evaluating performance, impact and ranking of IWRM strategies in the Jordan Valley", *Water Science and Technology*, Vol. 66 No. 2, pp. 1406-1415.

World Bank (2010), "Country Brief – Jordan", available at: http://web.worldbank.org/wbsite/external/countries/menaext/jordanextn/0,menupk:315140~pagepk:141132~pipk:141107~thesitepk:315130,00.html (accessed September 1, 2016).

Zekri, S., Kotagama, H. and Boughanmi, H. (2006), "Temporary water markets in Oman", *Agricultural and Marine Sciences – A Research Journal*, Vol. 11 No. 1, pp. 77-84.

Further reading

Wheeler, S., Bjornlund, H., Shanahan, M. and Zuo, A. (2008), "Price elasticity of water allocations demand in the Goulburn-Murray Irrigation District", *The Australian Journal of Agricultural and Resource Economics*, Vol. 52 No. 1, pp. 37-55.

Corresponding author
Ihab Hanna Sawalha can be contacted at: i.sawalha@aum.edu.jo

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**