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Economic implications of agricultural reuse of treated wastewater in Israel: A statewide long-term perspective

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A B S T R A C T

We develop an Israeli version of the Multi-Year Water Allocation System (MYWAS) mathematical programming model to conduct statewide, long-term analyses of three topics associated with agricultural reuse of wastewater. We find that: (1) enabling agricultural irrigation with treated wastewater significantly reduces the optimal capacity levels of seawater and brackish-water desalination over the simulated 3-decade period, and increases Israel's welfare by 3.3 billion USD in terms of present values; (2) a policy requiring desalination of treated wastewater pre-agricultural reuse, as a method to prevent long-run damage to the soil and groundwater, reduces welfare by 2.7 billion USD; hence, such a policy is warranted only if the avoided damages exceed this welfare loss; (3) desalination of treated wastewater in order to increase freshwater availability for agricultural irrigation is not optimal, since the costs overwhelm the generated agricultural benefits. We also find the results associated with these three topics to be sensitive to the natural recharge of Israel's freshwater aquifers, and to the rate at which domestic-water demand evolves due to population and income growth.

1. Introduction

Population growth has increased urban demand for freshwater and the need for sewage disposal, both of which motivate the agricultural reuse of wastewater. Wastewater is therefore perceived as a renewable resource for agricultural irrigation (Rutkowski et al., 2007), and its use is becoming common worldwide (Qadir et al., 2007). For example, in Israel, more than 85% of treated wastewater (TWW) is used for crop irrigation (IWA, 2012); in Spain, nearly 71% (Iglesias et al., 2010) and in California, about 20% of reclaimed wastewater is utilized in agriculture (Angelakis and Snyder, 2015). Thus, agricultural reuse of TWW substitutes for scarce freshwater sources, saves on fertilizer and energy costs through reuse of plant nutrients and trace elements (Dawson and Hilton, 2011), and its stable and drought-proof supply carries valuable agricultural benefits (Feinerman and Tsur, 2014). However, wastewater reuse is also associated with detrimental environmental and social implications (Hanjra et al., 2012), as well as negative health effects due to the presence of pathogens (Kazmia et al., 2008), heavy metals (Li et al., 2009), pharmaceuticals and other synthetic compounds (Ratola et al., 2012). As TWW differs from freshwater in salinity, pH, and concentrations of suspended solids and dissolved organic matter, TWW irrigation can change the soil's physical, biological and chemical characteristics (Lado et al., 2012). An increase in soil salinity can reduce plant growth (Dinar et al., 1986; Kan et al., 2002), and accumulation of chloride, sodium and boron may be toxic to the plants (Bresler et al., 1982). Long-term irrigation with TWW might increase soil sodicity, which in turn reduces soil-structure stability (Feigin et al., 1991; Levy et al., 2014).

Given these pros and cons, TWW reuse requires long-term planning and investments that affect water economies at the basin, aquifer and even statewide levels. It requires setting sewage-reclamation quality standards and agricultural application constraints that will account for health and food safety and long-run processes of soil and groundwater contamination; it further necessitates the continuous development of infrastructures for collecting and reclaiming sewage, and distributing the TWW outputs to farming areas. Accordingly, a pricing scheme that incentivizes the efficient use of TWW should be implemented, taking into account both the productivity and supply costs of TWW relative to its alternatives—freshwater and brackish-water sources.

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Being located at the boundary of a desert, and facing rapid and steady population growth, Israel's natural freshwater sources have fallen short of meeting the growing demand, particularly for domestic uses. In response, desalination plants have been installed to enhance and stabilize the freshwater supply, and freshwater allotments for agriculture have been cut, and replaced by TWW quotas (Kislev, 2011). Consequently, Israel is the country with the largest agricultural reliance on TWW, constituting about 40% of total agricultural water use (IWA, 2012); in comparison, TWW makes up 17% and 6% of the irrigation water in Spain and California, respectively (Goldstein et al., 2014). Moreover, Israel's water system connects, via the National Water Carrier, almost all of its major water resources into one operational system, which supplies water to almost all of its regions. This national water system essentially turns the country into one basin; that is, the net benefits associated with consuming a water unit at a particular location should be weighed against those derived by consuming this unit in a different place. These attributes make Israel a case of interest for many regions throughout the world that are facing growing water scarcity.

Our objective in this paper is to assess water-management and welfare implications of agricultural reuse of TWW in Israel from a statewide, long-term perspective. Specifically, we are interested in three particular topics: first, we assess the welfare contribution of agricultural reuse of TWW by evaluating the welfare loss that would occur if TWW irrigation were not available for agricultural applications. The second topic focuses on the assessment of potential long-term damage caused by TWW irrigation to soil properties and groundwater quality. To this end, we evaluate an upper value for these damages by computing the costs of avoiding them altogether through desalination of TWW. That is, TWW desalination is considered a mandatory pre-reuse treatment. Such a policy not only prevents the long-term damage, but also increases the amount of freshwater available for the agricultural sector. Thus, regardless of the long-term damage, desalination of TWW as a method for merely increasing agricultural production comprises our third topic: we search for the optimal level of TWW desalination for agricultural use, where the desalination costs are weighed against the agricultural benefits obtained by turning TWW into freshwater for irrigation.

Our analytical tool is the Multi-Year Water Allocation System (MYWAS) model (Fisher and Huber-Lee, 2011). The MYWAS is the extended multi-year version of the 1-year steady-state WAS (Water Allocation System) model (Fisher et al., 2005). It is a dynamic discrete-time non-linear mathematical programming model that searches for optimal water allocation and infrastructural investments along time and space, while taking into account a range of economic data, physical factors and constraints. Thus, our approach follows the growing number of studies that have adopted hydro-economic modeling to explore efficient water management (see reviews by Harou et al., 2009 and Booker et al., 2012). Such models aim to solve the complex problem of water management while integrating different areas of expertise into a coherent unified framework, including hydrology, engineering, economics, environmental effects and geography. For instance, Xu et al. (2001), Haruvy et al. (2008) and Rosenberg et al. (2008) have included wastewater reuse in hydro-economic models. A prominent example in terms of spatial scope, detail and complexity is the CALVIN (California Value Integrated Network) model (Draper et al., 2003; Jenkins et al., 2004). Similarly, the Israeli version of the MYWAS encompasses a detailed water-allocation network on a national scale, incorporates demand functions for domestic, industrial and agricultural uses, and enables agricultural reuse of TWW. Given the extensive agricultural use of brackish water and TWW in Israel, we incorporate into the model the impact of water quality on agricultural production, and capture the substitution between freshwater, brackish water and TWW.

We study the above three topics by comparing a baseline scenario and three variations of this scenario in relation to the topics under consideration, where under each scenario, the MYWAS searches for the optimal management for a period of three decades while accounting for forecasted changes in water demand and natural enrichment of groundwater stocks. The baseline scenario consists of TWW reuse, and no infrastructures for TWW desalination; our simulation suggests continuing the on-going policies in Israel of increasing seawater desalination and the substitution of agricultural freshwater by TWW. Compared to the baseline, the absence of TWW for agricultural reuse (first topic) exacerbates the reliance on seawater desalination for both urban and agricultural sectors' freshwater supply, causing a welfare loss of nearly 3.3 billion USD in terms of present values over the simulated 30-year time horizon.

As to the second topic, the upper bound of welfare loss associated with avoiding soil and groundwater damage through TWW desalination amounts to 2.7 billion USD; that is, a policy of mandatory TWW desalination is warranted only if the value of the avoided damage exceeds that welfare-loss valuation.

For the third topic, we conclude that under the current TWW-desalination technology and the agricultural substitutability between freshwater and TWW, increasing freshwater availability for agricultural irrigation through TWW desalination is too costly relative to the generated agricultural benefits. All of these results are found to be highly sensitive to the natural recharge level of freshwater aquifers. Thus, forecasts for drier climatic conditions in Israel (e.g., Krichak et al., 2011) are expected to increase Israel's reliance on TWW, and to entail negative welfare effects.

The next section briefly describes the MYWAS model; the third section details the scenarios and discusses the results; the fourth section provides key conclusions.

2. MYWAS – The Israeli Version

A complete formal description of the Israeli version of the MYWAS appears in Appendix A, and detailed topology and data are available in Reznik et al. (2016). In this section, we outline the main properties of the model.

Fig. 1 presents a stylized topology of the MYWAS tool. The water consumers are located in urban and agricultural zones. Urban zones obtain only freshwater for domestic and industrial uses, delivered either from renewable freshwater aquifers, or from plants that desalinate seawater and/or brackish water extracted from non-renewable saline aquifers. These freshwater sources also provide freshwater to the agricultural consumers, who may also consume brackish water directly from the saline aquifers, or TWW from wastewater-treatment plants that treat the sewage generated by the urban sector. Freshwater aquifers are enriched by natural recharge (precipitation), which also affects the demand for agricultural water use.

The model's detailed topology specifies the water sources (surface water, fresh and saline groundwater aquifers, desalination plants and wastewater-treatment plants), the regions of demand for agricultural

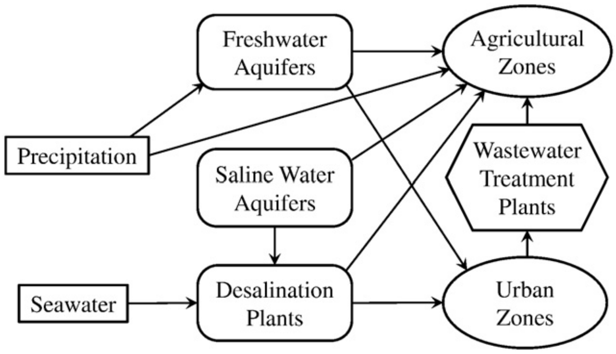

Fig. 1. Stylized scheme of the MYWAS tool.