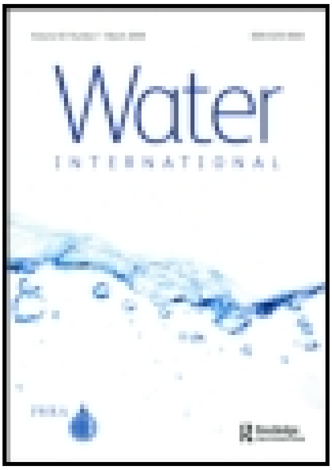

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Using water insecurity to predict domestic water demand in the Palestinian West Bank

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Household interviews were conducted in the Palestinian West Bank to examine the relationship between price elasticity, water insecurity and domestic water demand. Water insecurity weights were defined and quantified for each household for use in a multivariate regression model. The model demonstrated that (1) a water insecurity variable improves the ability to estimate price elasticity and that (2) increased water insecurity leads to higher levels of household water demand. The findings suggest that policy-makers can influence domestic water demand by addressing the supply constraints that underlie domestic water insecurity.

Keywords: water insecurity; price elasticity; domestic water demand; West Bank; multivariate regression; omitted variable bias

Introduction

This study examines the influence of water supply deficits on consumer behaviour by including water insecurity as a variable in a water demand model. It develops a subjective indicator scale to quantify water insecurity in domestic water demand in the Palestinian West Bank.

Decision-makers increasingly recognize the importance of water security as it relates to water supply management (EPA, 2013; Zeitoun, 2011). UN-Water (2013) asserts that water security is an essential component of human security and addressing it in the developing world can contribute to long-term governance stability.

However, studies of water security's converse, water insecurity, at the household level remain almost entirely consigned to the fields of anthropology and social work (Wutich & Ragsdale, 2008; Mason, 2012, Stevenson et al., 2012; see also Jepson, 2014, from the perspective of geography). Within the context of quantitative predictive models for water demand, the influence of water insecurity has not been examined, even in regions throughout the developing world where unreliable and inadequate water provision is common.

Previous studies have established user willingness to pay for improved domestic water reliability (Whittington, Lauria, & Mu, 1991; Lund, 1995; Griffin & Mjelde, 1997; Moffat, Motlaleng, & Thukuza, 2012). However, a variable measuring water delivery problems is difficult to quantify for demand analyses: Akram and Olmstead (2011) graded frequency of supply problems on a scale from 0 to 3 to examine the willingness to pay for

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supply improvements; Strand and Walker (2005) used fixed effects (also termed 'dummy variables') in a multivariate regression model to characterize the time periods a household typically received water. Stevenson et al. (2010) studied the relationship between water insecurity and psychological distress by assembling an insecurity scale using six survey components. Jepson (2014) used a cumulative scale procedure to measure dimensions of water security or insecurity. Wutich and Ragsdale (2008) and Hadley and Wutich (2009) measured progression across a set of indicators to examine water distress related to water insecurity.

This paper uses a subjective indicator model to quantify and evaluate domestic water insecurity. Households in the Palestinian West Bank experience water scarcity conditions that are both natural and man-made, and in this situation we discovered that water insecurity plays an important role in predicting the domestic water demand.

Method

A multivariate regression model is employed to compute the elasticity of the key variables driving domestic water demand in the West Bank. Elasticity measures the responsiveness of the dependent variable, in this case water quantity, to changes in the model's respective independent variables, such as price. Elasticity quantifies the magnitude at which increases or decreases in that variable will increase or decrease the demand. Price elasticity for domestic water demand is expected to be negative: increases in price cause consumers to purchase less water. The model for the West Bank incorporates several variables, including price and water insecurity, to calculate the elasticities of the model variables and to predict domestic water demand under various circumstances.

Though price elasticity is usually the focus of policy-makers, it cannot be calculated alone for two reasons: (1) attempts to examine the sensitivity using a one-at-a-time (OAT) analysis has severe limitations (Saltelli & Annoni, 2010); and (2) a common concern with sensitivity analysis is known as omitted variable bias (OVB) wherein important explanatory variables are not included in the models. OVB can lead to biased and inconsistent estimates of model coefficients, such as the coefficient for price elasticity of domestic water demand, which is the focus of this study. It arises when independent variables omitted in a regression model are correlated with both the independent variable of interest (here, price) and the dependent variable, domestic water demand. An effort was made to include a sufficient number of explanatory variables in the regression model to reduce the potential for OVB.

Survey design

Because West Bank residents purchase water from multiple sources, complete household water portfolios can only be captured through interviews. Guidance from the Palestinian Water Authority (PWA) framed the survey design. After testing and refining the survey questions in the summer of 2011, the survey received exemption status from the Institutional Review Board. In the summer of 2012 we administered 73 surveys during daytime weekday home visits across the West Bank. The PWA provided transportation, Arabic translators and community profiles to ensure we captured the various water access experiences in the 11 governorates. After selecting the communities, we selected households based on the presence of an adult at the time of the community visit. The survey included quantitative questions for data purposes and open-ended questions to encourage discussions of more nuanced topics.

The survey recorded household demographics, such as location, local governance, income bracket, number of household members and children under five years of age. Respondents provided water pricing structures, the infrastructures used in obtaining and storing water, and purchased water quantities for each source. Further questions examined accrued water debt and the perceptions of billing accuracy and water quality, tactics for reusing water within the household, and prompted recall (Wutich, 2009) of demand differences between summer and winter months. The survey also included a choice experiment to anticipate the household's response to various scenarios of water availability and pricing.

Survey procedure

Surveys varied between 20 and 45 minutes each. Respondents were not offered any type of reimbursement for participation. Some respondents provided water bills to validate their answers, but many did not; furthermore, West Bank customers receive billing statements only for municipal water, not for other sources like tankers and cisterns. To counter the difficulty in estimating water demand, surveys questions incorporated redundancy to verify that respondents provided consistent answers. The surveys revealed important details about the tactics, coping mechanisms and struggles to obtain adequate water quantities at the household level. A subset of 63 surveys with summer data and 64 with winter data contains sufficient information for analysis.

Explanatory variable selection

A household water demand analysis requires careful selection of the model's variables. These explanatory variables provide the quantitative values upon which the multivariate regression is based. Espey, Espey, and Shaw (1997), Arbués, García-Valiñas, and Martínez-Espiñeira (2003), Worthington and Hoffman (2008), and House-Peters and Chang (2010) review models for estimation of domestic water demand.

To guide our selection of potential variables for modelling, we summarized previous domestic water demand studies along with their respective predictor variables (Table 1). Not all the examined variables improve domestic water demand models: some showed ambiguous predictive power, whether because of null relationships in single studies or because different researchers found contradicting relationships. The citations are not intended to be exhaustive for each explanatory variable outlined in Table 1. We could not find any previous domestic water demand modelling studies that considered the impact of household perceptions of water insecurity.

For the price variable, the treatment of pricing under block rate structures due to municipal rates or tailored water portfolios has long divided scholars of demand elasticity (Arbués et al., 2003). Rather than using the average price or the marginal price alone, this study follows Taylor (1975) and Nordin (1976) and their successors in employing the *difference* variable (D), representing the monetary difference between actual water payments and the amount consumers would have paid if all the water had been billed at the last price of purchase, the marginal price. Because the price of water is a step function, water supply is a discrete continuous choice, meaning the unit cost is discrete even as the quantity is continuous. Figure 1 shows the D value's relationship with a household's supply curve. D equals the total monetary amount saved by buying water from sources costing less than the marginal price within the unit timeframe. Note that any household has a distinct supply curve and thus a distinct D value.

Table 1. Potential variables of domestic water demand.

Examined variable	Example paper that examined it
Water demand (Q)	
Per capita domestic demand	Almutaz, Ajbar, & Ali (2012), Mazzanti and Montini (2006), Bell and Griffin (2011)
Household consumption	Al-Najjar et al. (2011), Kenney, Goemans, Klein, Lowrey, and Reidy (2008), Dandy, Nguyen, & Davies (1997)
Urban (residential and industrial/commercial) demand	Bell and Griffin (2011)
Billing	
Average price	Kenney et al. (2008), see the list in Arbues et al. (2003)
Marginal price	Taylor (1975), see the lists in Arbues et al. (2003) and Worthington and Hoffman (2008). See also Griffin and Martin (1981)
Marginal price and difference variable	Nordin (1976). See the lists in Arbues et al. (2003) and Worthington and Hoffman (2008)
Pricing structure	Espey et al. (1997), Olmstead, Hanemann, and Stavins (2003). See Barberán and Arbués (2009) for pricing structure explanations
Frequency of billing	Stevens, Miller, and Willis (1992)
Shin pricing	Shin (1985), Nieswiadomy (1992)
Household knowledge of pricing	Gaudin (2006)
Water tariff not included in the model	Almutaz et al. (2012)
Considering free allowances	Dandy et al. (1997)
Income or income indicators	
Household income	Salman et al. (2008)
Per capita income	Mazzanti and Montini (2006)
Number of rooms	Grafton, Ward, To, and Kompas (2011)
Number of bedrooms	Kenney et al. (2008)
Number of bathrooms	Salman et al. (2008)
Property value	Hewitt and Hanemann (1995), Dandy et al. (1997), Arbués et al. (2003)
Plot size	Dandy et al. (1997)
Education level of the head of the household	Grafton et al. (2011), Jones and Morris (1984), Al-Najjar et al. (2011), Salman et al. (2008)
House ownership versus renting	Espey et al. (1997), Kenney et al. (2008)
Have a telephone	Strand and Walker (2005)
Number of cars	Bar-Shira, Cohen, and Kislev (2005), Jones and Morris (1984), Mimi and Smith (2000)
Age of the house	Kenney et al. (2008)

(*continued*)

Table 1. (*Continued*).

Examined variable	Example paper that examined it
Environmental	
Precipitation	Espey et al. (1997), Maidment and Miaou (1986), Martinez-Espiñeira (2002)
Evapotranspiration	Espey et al. (1997)
Normalized Difference Vegetation Index (NDVI) (Landsat)	Current study
Normalized Difference Water Index (NDWI) (Landsat)	Current study
Normalized Difference Water Index 2 (MNDWI2) (Landsat)	Current study
Modified Normalized Difference Water Index (MNDWI) (Landsat)	Current study
Seasonal dummy	Espey et al. (1997)
Temperature	Espey et al. (1997), Al-Qunaibet and Johnston (1985), Billings (1987)
Maximum temperature	Almutaz et al. (2012), Bell and Griffin (2011), Gutzler and Nims (2005)
Minimum temperature	Bell and Griffin (2011)
Average maximum temperature	Bell and Griffin (2011)
Average minimum temperature	Bell and Griffin (2011)
Temperature above a certain threshold	Gaudin (2006)
Minutes of sunshine	Al-Qunaibet and Johnston (1985)
Wind speed	Al-Qunaibet and Johnston (1985)
Thornthwaite's potential evapotranspiration	Dandy et al. (1997)
Ratio of warm to cold days	Grafton et al. (2011)
Summer rain	Griffin and Chang (1990)
Altitude	Mazzanti and Montini (2006)
Drought conditions	Kenney et al. (2008)
Demographic	
Household size	No examples were found of studies excluding this variable or an indicator for it, see Salman et al. (2008), Schleicha and Hillenbrand (2009), and the list in Corbella and Pujol (2009)
Population density	Espey et al. (1997), Mazzanti and Montini (2006), Gaudin (2006)
Cultural background	Griffin and Chang (1990), Smith and Ali (2006), Pfeffer and Mayone Stycos (2002). See also Bar-Shira et al. (2005)
Number of children	Grafton et al. (2011), Mazzanti and Montini (2006)
Number of adults	Grafton et al. (2011), Martínez-Espiñeira (2003), Mazzanti and Montini (2006)

(*continued*)

Table 1. (*Continued*).

Examined variable	Example paper that examined it
Age of the respondent	Grafton et al. (2011), Kenney et al. (2008)
Type of house	Al-Najjar et al. (2011). See also Arbués et al. (2003)
Population growth rate	Nieswiadomy (1992)
Religion	Smith and Ali (2006)
Water use	
Irrigable area per dwelling unit	Howe and Linaweaver (1967), Mimi and Smith (2000)
Pool ownership	Dandy et al. (1997). See the list in Corbella and Pujol (2009)
Garden size	Nieswiadomy and Molina (1989), Lyman (1992), Hewitt and Hanemann (1995)
Sprinkler system	Lyman (1992)
Irrigation season during the bill cycle	Kenney et al. (2008)
Infrastructure	
Water-saving devices installed (toilet, shower)	Grafton et al. (2011), Kenney et al. (2008)
Landscape and irrigation technologies	Renwick and Archibald (1998)
Use of a well	Schleicha and Hillenbrand (2009)
Home construction year	Nieswiadomy, 1992
Indicator appliances (toilets, taps)	Al-Najjar et al. (2011), Mimi and Smith (2000)
Water delivery time	Strand and Walker (2005)
Type of water access/reliability	Strand and Walker (2005) (dummy variables), current study
Attitudes	
Environmental concerns	Grafton et al. (2011), Domene and Saurí (2006), Gilg and Barr (2006)
Participant in environmental groups	Grafton et al. (2011)
Leader in an environmental group	Grafton et al. (2011)
Voter dummy	Grafton et al. (2011)
Policies	
Water restrictions	Renwick and Green (2000)
Water rationing (dummy variables)	Strand and Walker (2005)
Holiday occurrence during the bill cycle	Kenney et al. (2008)
Number of commercial enterprises in the community	Mazzanti and Montini (2006), Musolesi and Nosvelli (2007)
Maximum capacity the city can supply	Nieswiadomy (1992)
Conservation campaigns in the media	Agras, Jacob, and Lebedeck (1980), Renwick and Green (2000). See also Syme, Nancarrow, and Seligman (2000), Martin, Ingram, Laney, and Griffin (1984) and Gegax, McGuckin, and Michelsen (1998)

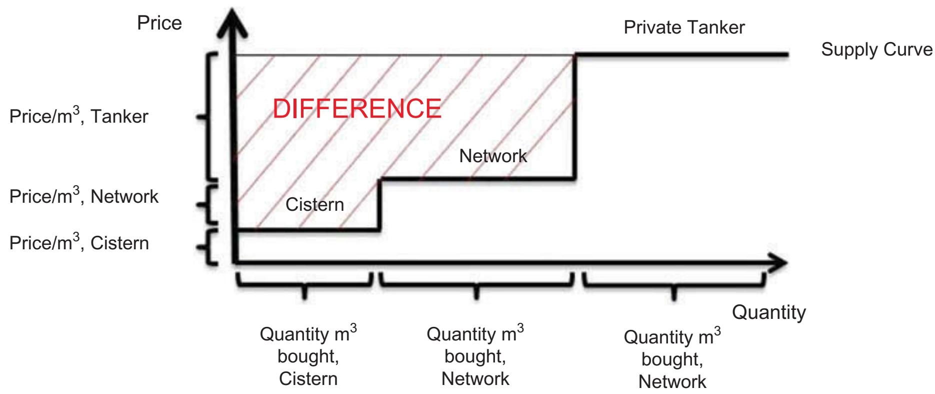

Figure 1. Example of a *difference* value for a household supply curve.

Household size was also included as an explanatory variable, as were numerous environmental variables such as temperature, elevation and precipitation which can influence the demand of household water (Table 1). Environmental conditions vary considerably across the West Bank. To characterize these variations, a geographic information system (GIS) was used to parameterize satellite imagery with Aster, Landsat and MODIS satellite data. We analysed raster images in GIS using the *Zonal Statistics as Table* tool to find minimum, maximum and mean values of each environmental raster data set as additional variables for the regression model.

For satellite data variables unaffected by land use, such as precipitation, surface temperature and elevation, all rasters were sampled within each community to generate parameter data. Figure 2 shows a raster of average of annual precipitation from 1981 to 2010. Since it does not rain during the summer months, the mean values for precipitation were applied to winter data and set to zero during the summer.

To obtain variables representing the natural environment of the communities, we created 1.5-km buffers around each community which excluded irrigated land before using the *Zonal Statistics as Table* tool in GIS.

In the remote sensing software ENVI, we applied band maths operations (Mather & Koch, 2011) to create indices related to water content. These indices derive from satellite imagery subdivided into spectral bands which can be combined mathematically to represent environment indicators, including water and greenness of vegetation. The analysis used cloudless summer and winter Landsat satellite images from 1999 and 2000, respectively (Figure 3). The following Landsat 7 spectral band math operations quantify environmental variables for the regression model:

$$Normalized\ Difference\ Vegetation\ Index\ (NDVI) = \frac{NIR - Red}{NIR + Red}$$

$$Normalized\ Difference\ Water\ Index\ (NDWI) = \frac{1 - SWIR/NIR}{1 + SWIR/NIR}$$

$$Normalized\ Difference\ Water\ Index\ 2(NDWI2) = \frac{1 - NIR/Green}{1 + NIR/Green}$$

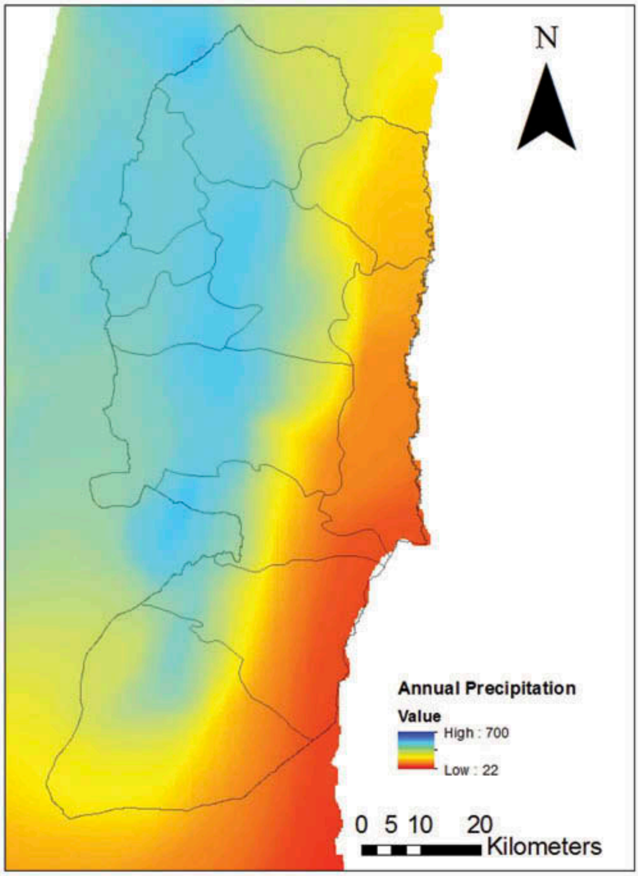

Figure 2. Annual precipitation raster.

$$\mathit{Modified\ Normalized\ Different\ Water\ Index}(MNDWI) = \frac{1 - SWIR/Green}{1 + SWIR/Green}$$

where NIR is near infrared (band 4); Red is red (band 3); SWIR is shortwave infrared (band 5); and Green is green (band 2).

Water insecurity in the West Bank

These variables represent many aspects of the experience of water in the West Bank, but given the respondent's frequent reference to water shortages and service disruptions, we sought to quantify this problem within the model. Herein we provide the context that led to our development of the water insecurity variable.

The 1995 Oslo Accords, signed by Israeli and Palestinian representatives, created the PWA to manage the water resources of the future Palestinian state (Aggestam & Sundell-Eklund, 2014; Oslo, 1995; Smith, 2007). Today, a persistent summer water deficit for

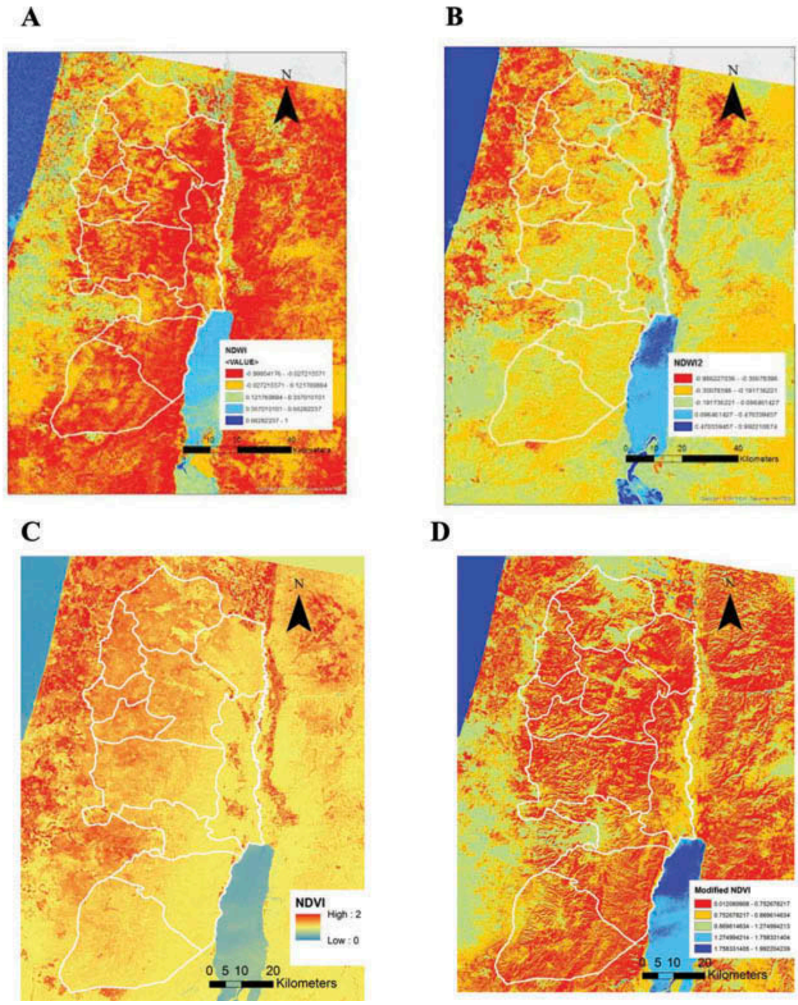

Figure 3. Rasters for (A) NDWI, (B) NDWI2 NDVI and (C) MNDWI, January 2000.

many Palestinian households results from the confluence of natural aridity, population growth, development, power asymmetry with neighbouring Israel, infrastructure problems and governance mismanagement. These factors do not equally contribute to the domestic consumption deficit, nor are they equivalent in terms of the ease with which they can be addressed and ameliorated.

Metal and plastic tanks crowd the rooftops of Palestinian households in the West Bank. The tanks store water when the networks are empty and can also store water purchased from private tankers. Storage ensures access even in times without service to mitigate the effects of the discontinuous supply.

Development scholars have long argued that water supply problems are tied not only to scarcity but also to mismanagement in delivery (Biggs, Duncan, Atkinson, & Dash, 2013; Ohlsson, 2000). Leakages and ineffective cost recovery can diminish the institutional capacity to deliver water (Meinzen-Dick & Appasamy, 2002; Srinivasan, Gorelick, & Goulder, 2010), creating unreliable water supplies for domestic users.

These supply disruptions especially impact consumers already coping with scarcity. Collins, Morduch, Rutherford, and Ruthven (2009), in a discussion of the finances of the poor, emphasize that *irregular* wages (access) compound the hardships of inadequate income (quantity).

Strand and Walker (2005) examine the impacts of intermittent supply in their water demand regression and find that rationed supply does not necessarily affect demand due to sufficient storage coping strategies, which can negate service unreliability (see also Christodoulou & Agathokleous, 2012). However, they find considerable social costs inherent for unconnected consumers who regularly devoted time to securing water, had variable water quality and could not always use water in 'normal' ways like showering. For further consequences of intermittent water supply, see Yepes, Ringskog, and Sarkar (2001), Coelho, James, Sunna, Abu Jaish, and Chatila (2003), Myers (2003), Totsuka, Trifunovic, and Vairavamoorthy (2004), Lee and Schwab (2005), Vairavamoorthy, Gorantiwar, and Mohan (2007), Baisa, Davis, Salant, and Wilcox (2010), Majuru, Mokoena, Jagals, and Hunter (2011), and Abu-Madi and Trifunovic (2013).

Though water scarce, Israel–Palestine does not have a shortage of *domestic* water (see Allan, 2002, and Zeitoun, 2008, regarding trades-offs between agricultural and domestic water), especially considering recent innovations in desalination. While technical limitations contribute to unreliable water provision, governance and social structures can also impact water access. The Santa Cruz Declaration (2014) highlights the indirect influence of social inequity on water supply. Zeitoun (2008) asserts that water access can imply who has power within a system and who does not. Ennis-McMillan (2001) suggests that distress over water scarcity incorporates perceptions of authorities using water as a source of power, such that lack of water delivery can become a social injustice. Stevenson et al. (2012, p. 393) finds water insecurity to be 'determined not only by physical access and adequacy of supply, but also by the stress inherent in negotiating with *inequitable* systems of water regulation' (emphasis added) (see also Vásquez, 2012; and Permenter, 2013).

Inequitable water access is an omnipresent reality in the West Bank where Israeli settlements are highly visible to Palestinians. Common water suppliers prioritize the settlements (Selby, 2003), not Palestinian consumers. Settler water consumption is thought to be six (Diabes, 2003; Koek, 2013) to nine (Freijat, 2003) times greater than their Palestinian neighbours. Rabbo (2010) suggests that Palestinians perceive Israel's provision of water as another form of occupation and domination. The water allocation framework set forth in the Oslo Accords creates a situation where the Palestinian government cannot exercise full autonomy over its water resources and gives Israel implicit or explicit control over much of the West Bank's water at some point in the distribution process (World Bank, 2009; Zeitoun, 2008).

Quantifying water insecurity as a variable

With consideration of the water supply system dynamics, we define resource insecurity as the combination of consumers' resource vulnerability and a lack of confidence that the entity controlling the resource is invested in the beneficiary's derived welfare. We expand this definition below, as applied specifically to the demand of household water.

Vulnerability is the first component of water insecurity. Hashimoto, Stedinger, and Loucks (1982) define vulnerability as a measure of the likely consequence of system failure. The West Bank's natural aridity imposes severe consequences for failure in water delivery. However, insecurity and vulnerability may overlap, but they remain distinct concepts because consumers can still have confidence in their water supply even if they understand it to be vulnerable, as in the south-western United States.

The second component of water insecurity incorporates the influence the consumer(s) can exert over the water-controlling entity or purveyor when advocating for improved supply access: the confidence that the water supplier is invested in the beneficiary's derived welfare. Medical anthropology has defined health as 'access to and *control over* the basic material and non-material resources that sustain and promote life' (Baer, Singer, & Susser, 1997, p. 5; emphasis added). Some study participants stated their unwillingness to discard rooftop storage tanks, even when their water came continuously. They attributed this hesitation to their uncertainty about future supply and overall lack of confidence in the water supplier and its dependence on Israeli consent. These responses helped frame our definition for water insecurity as vulnerability coupled with consumers' perceptions of power structures and the supplier's incentives.

We used water supply characteristics to develop a subjective indicator scale and corresponding values for the regression model. The water insecurity scale characterizes household water supplies on a continuum from least insecure to most insecure (Table 2). Each interview received a value corresponding to the household's water infrastructure at the time of reference (peak summer/non-peak winter).

Using this definition, we hypothesized that water demand in the West Bank is determined by household demographics, water pricing and the physical environment, but also by consumers' perceptions of their capacity to control their own water supply, that is, to perceptions of water insecurity.

Table 2. Subjective indicator scale for water insecurity.

	Least insecure ... to ... Most insecure					
Associated costs	Constant supply – cistern	Constant supply – network	Reliable delivery – network	Reliable delivery – tanker	Unreliable network, supplemented by a tanker	Unreliable network – waiting for water
Storage infrastructure (maintenance, space, losses, contamination)	Yes	Yes[a]	Yes	Yes	Yes	Yes
Water payment (NIS/m^3)	No	Yes	Yes	Yes	Yes	Yes
Reliance on external players for the water supply	No	Yes	Yes	Yes	Yes	Yes
Risk of shortage	No	No[a]	Yes	Yes	Yes	Yes
Advance planning	No	No	No	Yes	Yes	n.a.
Loss of control, psychological distress	No	No	No	No	Yes	Yes
Associated insecurity weight	.1	.2	.4	.5	.6	.8

Notes: [a]A household with a constant network supply could be expected to dispense with its storage infrastructure. However, in the West Bank families with constant water tend to be connected to Israeli settlement water supplies. Because that supply depends on another nation's caprices, interviewed households stressed keeping their storage infrastructure. The storage investments may be an indicator of awareness of Israeli control over water sources – akin to the social injustice noted by Ennis-McMillan (2001) in Mexico.
n.a., Not applicable.

Limitations

This study includes limitations: the survey size was small and the sampling method perhaps led to selection bias of interviewees by over-representing vulnerable populations. Much of the data came from self-reporting, often concerning quantities and prices that cannot be cross-referenced. The cistern data are not well documented and required several informed assumptions to determine usage and pricing. The environmental satellite images are dated and, with the exception of precipitation, consist of snapshots in time rather than monthly averages that might be more representative of the study's time periods. GIS screening of the irrigation for community buffers was not entirely effective. However, the use of satellite imagery has allowed this study to include variables that were not otherwise available.

Model analysis

We incorporated a number of explanatory variables derived from survey data and GIS environmental data into a multivariate regression analysis with the following regression model formulation:

$$\ln(Q) = a + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \ldots + \beta_n \ln(X_n)$$

This power law model formulation is widely used (Dandy et al., 1997; Hewitt & Hanemann, 1995; Nieswiadomy, 1992; Strand & Walker, 2005; see also the discussions in Arbués et al., 2003) because it results in model coefficients β_n representing the non-dimensional water demand elasticity corresponding to each variable X_n.

Table 3 summarizes the model, demonstrating the highest goodness of fit and the lowest model coefficient *p*-values among models tested with various explanatory variable combinations. Diagnostic evaluation of the model residuals revealed that they are approximately independent, homoskedastic and well approximated by a normal distribution. All variance inflation factors (VIFs) are less than 5, indicating no multicollinearity (Helsel & Hirsch, 2002).

The model described in Table 3 can be summarized as:

Table 3. Results of the regression model.

Predictor	Coefficient	SE coefficient	*T*-value	*p*-value (calculated)[a]	VIF
Constant	3.104	0.360	8.63	$2.265*10^{-14}$	
ln(*Price*)	−0.2766	0.0894	−3.09	0.002	2.48
ln(*HouseholdSize*)	0.6835	0.0785	8.71	$1.465*10^{-14}$	1.26
D	0.0566	0.0152	3.72	$2.987*10^{-4}$	1.26
ln(*MNDWImax*)	1.360	0.366	3.72	$2.987*10^{-4}$	2.74
ln(*NDVImax*)	−1.560	0.689	−2.26	0.025	1.36
ln(*Precip*)	−0.1703	0.0260	−6.54	$1.309*10^{-9}$	2.78
ln(*Insecurity*)	0.402	0.136	2.94	0.004	2.21
R^2 = 58.43%		Adjusted R^2 = 55.99%		Predictive R^2 = 53.18%	

Notes: [a]Values were calculated in Mathcad using 2 × (1 – pt(*T*,*n* – 1)) or 2 × pt(*T*,*n* – 1) for negative *T*-values. VIF, variance inflation factor: a measure of collinearity or redundancy in the variables because of relationships between them.

Source: Adapted from the American Heritage ® Medical Dictionary Copyright © 2007, 2004 by Houghton Mifflin Company.

$$Q = e^{3.104} * Cost^{-0.276} * House^{0.83} * e^{0.0566D} * MNDWImax^{1.36} * NDVImax^{-1.56} * Precip^{-0.1703} * Insecurity^{0.402}$$

where Q is household water demand (m^3/household/month); *House* is the number of residents in the household; D is the per capita monthly money savings of water bought at prices other than the last price (new Israeli shekels – NIS); *Price* is the last price (which is not always the highest price) paid for water (NIS); *MNDWImax* is the maximum instantaneous MNDWI value for the 1.5 km buffer around each city, excluding areas screened out for irrigation or other urban regions; *NDVImax* is the maximum instantaneous NDVI value in the 1.5-km buffer around each city; and *Precip* is the mean annual precipitation (mm) within each community for winter and set to zero during summer. To take the natural log of 0 values, a value of 1 was added to all millimetre values.

Results

The final model summarized in Table 3 results in a price elasticity of domestic water demand of −0.277 with a standard error (SE) of 0.089, corresponding to a 95% confidence interval of −0.187 to −0.366 with an adjusted R^2 of 56%.

Household size shows positive elasticity because as families grow water consumption increases. Similarly, as the amount of money discounted, D, increases, the amount of water consumed increases, though this remains part of the price effect. MNDWI, a wetness index, has positive elasticity; while NDVI, a measurement of green vegetation, shows increased water demand as NDVI values decrease with drying vegetation. Precipitation shows negative elasticity because more rain results in less water demand. Precipitation also incorporates seasonal effects, since there is no precipitation in the summer.

The model shows that water insecurity has positive elasticity, meaning that when all other factors – including price – are held constant, houses that are more water secure will demand less water. Similarly, higher water insecurity results in higher water demand, a result discussed below.

We compared the results of our model with the same model without water insecurity. The goodness of fit as evidenced by R^2 increases with the inclusion of water security. In addition, the model with water insecurity produced a p-value for the price variable of 0.006. Without the insecurity variable, the same model resulted in $p = 0.148$ for the price variable, meaning water prices did not have a statistically significant impact on water demand. Thus, including insecurity in the model helps explain the relationship between price and quantity. Furthermore, when insecurity is included in the model, there was over a 279% increase in price elasticity from −0.099 to −0.276 due to the important effect of OVB.

Not all the explanatory variables originally included had statistically significant relationships with household water demand, and thus were not included in the final model. The variables showing low explanatory power included income, number of children, land surface temperature, NDWI, NDWI2 and elevation. The following section discusses the model results and the role of water insecurity in terms of its ability to explain household water demand, as demonstrated within our regression model.

Discussion

The water insecurity variable has two impacts on the domestic demand model: water insecurity appears to drive higher water demand; and its inclusion enables price to have greater explanatory power. This section explores these results in the context of the water supply situation in the West Bank.

The notion of higher water demand due to insecurity, as shown by our model, contrasts with the more intuitive and widespread assumption that water rationing results in constrained water consumption. However, elevated demand has previously been observed for intermittent water (Lee & Schwab, 2005; McIntosh, 2003), without specifying for water insecurity. Consumers may leave taps open (Coelho et al., 2003), collect the maximum amount of water available during network operating hours (Chandapillai, Sudheer, & Saseendran, 2012), or may purchase more water to protect themselves from future shortages or because emergency supplies such as tankers only come in bulk quantities. The World Health Organization (WHO) (2005) suggests that all intermittent supplies should be considered contaminated, and accordingly consumers may also dump 'stale' water when freshwater arrives (McIntosh, 2003; Myers, 2003). These findings demonstrate inefficiencies stemming from an intermittent and unreliable supply.

Even with water storage for municipal supply, replenishment deliveries can become unreliable enough to engender water insecurity. During the interviews, one household anecdotally described disconnecting from an unreliable network to buy from more reliable but more expensive tankers, consistent with Grey and Sadoff's (2007) observations about risk aversion in securing water supply.

Furthermore, the West Bank is not strictly a rationing situation due to available tanker water. Such auxiliary sources can be comparably priced or much more expensive, so families must weigh tanker purchases against the expectations of cheaper water arriving through network delivery. Unreliability, which can foster water insecurity, can cause families to spend much more money on water than they might have with more knowledge or control over the municipal supply.

We suggest that insecure consumers buy more water because they are unable to predict and/or control their future access. For example, if water delivery continues after all the storage tanks are filled, water-related tasks can be subsequently performed in haste, leading to inefficient water use. Baisa et al. (2010) discuss household consumption practices in uncertain service conditions. The degree to which each of these factors contributes to higher water demand, or if there are additional contributing factors, is presently unknown. Our results indicate that further research is needed to investigate the relationship between insecurity and water demand.

Similarly, we propose that, like the impact of water scarcity, water *access* insecurity raises consumers' willingness to pay. The only previous known study of domestic water demand in the West Bank found consumers in Ramallah to have a price elasticity of −0.6, higher than the results of this study, though still relatively inelastic (Mimi & Smith, 2000). In Israel, Bar-Shira et al. (2005) calculated price elasticity at −0.47. Al-Najjar, Al-Karablieh, and Salman (2011) estimated Jordanian domestic water price elasticity at between −0.52 and −0.67. Our model results in lower price elasticity with a range of −0.187 to −0.366. Palestinians generally consume less domestic water than their neighbours (Bullene et al., 2013), which is congruous with the lower elasticity calculation. Lower elasticity can also be an indicator of poverty. Cairncross and Kinnear (1992) found in Khartoum, Sudan, that poor families paying between 17% and 56% of their income on water did not change their water consumption habits based on price, compensating instead by buying less food. An average Palestinian spends about 8% of their income on water, twice the global average, and some households, and often the very poor, spend up to 45% (Glover & Hunter, 2010). Around the world, the unconnected poor pay a huge premium for water access (Briscoe, 2009).

The challenge of water access could explain why the water price variable had low explanatory power in the absence of the water insecurity variable. A perceived lack of control over water delivery suggests conditions of *learned helplessness* (Seligman & Maier, 1967) to explain the declining value of unreliable water. McGuire and Kable (2013) examined the process of waiting for reward and found that the conviction of imminent arrival fades as delays unfold, discouraging persistence in waiting further. They found that changing one's mind about delaying gratification can be a rational decision in situations when the timing of the payoff is uncertain. In the Palestinian context, water-insecure consumers may be more likely to buy more expensive tanker water if they are uncertain whether they can stretch their resources to the next unknown delivery time.

Because of this uncertainty, the authors suggest that the concepts of insecurity and overcompensation, meaning the exaggerated correction of a real or imagined deficiency, are fundamentally coupled. This could explain the choice to augment water supply under uncertainty and link the opposing ideas of lowered consumption under rationing and inefficient use under insecurity.

The United Nations is investigating links between governance and water security (UN-Water, 2013); the Asian Development Bank (ADB) (2013) asserts that government policies can create consumer confidence for a variety of customers. As has been demonstrated in this paper, the issue is inherently multidisciplinary, spanning anthropology, public health, political science, engineering and other areas.

Conclusions

To our knowledge, this study is the first to examine the influence of water insecurity on domestic water demand and price elasticity. We developed a multivariate model to predict consumer water demand as a function of numerous explanatory variables representing the environment, household demographics, water prices and water insecurity. We found that including an explanatory variable that characterizes perceptions of insecurity associated with household water access led to significant improvements in our ability to estimate both price elasticity and household water demand across the West Bank.

We found a price elasticity ranging from −0.187 to −0.366, and that price elasticity only has significant explanatory power when the water insecurity variable is included in the model. Our findings show that water insecurity has positive elasticity, suggesting that improved service predictability and consumer confidence, even without changing the quantity of water supplied, may reduce demand by allowing consumers to exercise control over their consumption of water. In the absence of such controls, the consequences of water insecurity may include redundancy, inefficiency and human suffering (Ennis-McMillan, 2001; Wutich & Ragsdale, 2008).

Recommendations

Gaudin (2006) and Salman, Al-Karablieh, and Haddadin (2008) suggest that when price elasticity is low enough, priced-based policies cannot serve as a conservation tool for municipal water, limiting opportunities for policy interventions in demand-side management. Our analysis of water insecurity suggests that policy-makers can still influence water demand through non-price measures such as improving reliability and buoying consumer confidence. As stated, reliable water has more value and additional reliability may decrease perceptions of water insecurity over time. Our findings indicate that the secure provision of water may reduce demand and thus the household expenditures for water, which especially influence hardship for the poor.

UN Water (2013) provides broad recommendations to encourage water security and we advise incorporating social aspects of water scarcity and insecurity, like equity issues, in future policy and technical discussions. The issue at stake both includes and transcends traditional infrastructure and supply problems to encompass consumers' perceptions of injustice in the water situation and their reaction against it. Bradley and Bartram (2013, p. 6) state, 'the combination of social, managerial, engineering and political factors that determine the acceptability of [unreliable and infrequent supply] is inadequately understood', but this study argues that it is rooted in water insecurity, that is to say, vulnerability and perceptions of power.

For Israel–Palestine, addressing water insecurity will entail infrastructure improvements and convincing both sides that Israel can benefit from relinquishing more water and autonomy over water to the Palestinians to enable improved reliability and consumer confidence. Improving water supply jointly can also build trust over time (Brooks, Trottier, & Doliner, 2013), which the Oslo-appointed Joint Water Committee has not achieved (Selby, 2013). The integrated economic water resource allocation model developed by Fisher et al. (2005) for the region demonstrates how cooperation can generate mutual benefits. Critical to the completion of such an integrated model is reliable estimates of price elasticity such as those obtained through our demand model.

The full implications of water insecurity in the regression model would be better understood with a portfolio management study such as that conducted on poverty finances by Collins et al. (2009), although the Palestinian experience with water insecurity is not a problem limited to the poor. It pervades households everywhere based on location, season, governance and local resources.

Policy-makers have many options to improve water access in scarce regions. While pricing policies and conservation campaigns are carried out across the Middle East, this study suggests that improving water supply reliability and consumer confidence can be additional tools of policy intervention to influence consumer behaviour. Our findings indicate that a secure provision of water reduces demand and thus the expenditures for water for the poor. Further study is needed to understand the mechanisms that cause insecure households to buy more water. Meanwhile, the water situation in the West Bank is already dire and future climate change, economic growth and development will only exacerbate existing conditions. Decision-makers have the opportunity to understand consumer perspectives and to implement beneficial policies for the people dependent on them for water.

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