# Accounting for Water Insecurity in Domestic Water Demand Modeling

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**Stephanie Elisabeth Galaitsis**

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**Advisors: Richard Vogel, Annette Huber-Lee, Elena Naumova**

***Abstract***

Future water planning efficacy depends upon the predictability of the systems under management. Water demand management uses price elasticity estimates to predict consumer demand in relation to water pricing changes, but studies have shown that many additional factors effect water consumption. Development scholars document the need for water security, however, much of the water security literature focuses on broad policies which can influence water demand.  Previous domestic water demand studies have not considered how water security can affect a population's consumption behavior.

This study is the first to model the influence of water insecurity on water demand. A subjective indicator scale measuring water insecurity among consumers in the Palestinian West Bank is developed and included as a variable to explore how perceptions of control, or lack thereof, impact consumption behavior and resulting estimates of price elasticity.

A multivariate regression model demonstrates the significance of a water insecurity variable for data sets encompassing disparate water access. When accounting for insecurity, the $R^2$ value improves and the marginal price a household is willing to pay becomes a significant predictor for the household quantity consumption. The model denotes that, with all other variables held constant, a household will buy more water when the users are more water insecure. Though the reasons behind this trend require further study, the findings suggest broad policy implications by demonstrating that water distribution practices in scarcity conditions can promote consumer welfare and efficient water use.

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## *Introduction*

The 1995 Oslo Accords, signed by Israeli and Palestinian representatives, created the Palestinian Water Authority (PWA) to manage the water resources of the future Palestinian state (Oslo, 1995, Smith, 2007). Today, a persistent summer water deficit for many Palestinian households results from the confluence of natural aridity, population growth, development, power asymmetry with neighboring Israel, infrastructure problems and governance mismanagement. These factors do not equally contribute to the domestic consumption deficit, nor are they comparable in terms of the ease with which they can be addressed and ameliorated.

Household water is an essential feature of every human settlement in the world and the study of domestic water demand is multi-faceted, spanning disciplines from anthropology, economics, psychology, biology, chemistry, and water resources engineering. Where politics has failed to solve the compounding water problems in the West Bank (World Bank, 2009), economic analysis can reveal alternatives.

In the book *Liquid Assets*, Fisher and Huber-Lee et al. (2005) prescribe a model for water resource allocation between Israel, Jordan, Gaza and the West Bank that maximizes the benefits accrued through various water activities in the forty-five political subdivisions of the three riparians. Viewing water as an economic asset, its allocation can be treated as a non-zero sum game where all the parties benefit to some degree from cooperating instead of acting unilaterally to allocate the region's scarce water (Fisher et al. 2002).

Simulation and optimization models can quantify the value of cooperation only when consumer response to change in water availability is understood and rendered predictable within a model. This paper aims to derive the relationship between domestic water demand and its various exogenous predictors for application in models such as the Multi-Year Water Allocation Systems (MYWAS) (Fisher et al. 2005). Using data from administered surveys, we employ a multivariate regression to model domestic water demand in the West Bank as a function of the demographic, economic, environmental and governance factors poised to impact that demand.

This study contributes to the domestic water demand literature by using water insecurity measures as a variable. Gray and Sadoff (2007) define its converse, water security, as the "availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies." The UN defines water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN Water, 2013). Zeitoun (2012) argues that these definitions are insufficient because they fail to address the social consequences arising from distribution inequities. The notion of insecurity developed in this paper considers resource scarcity as part of a social context.

Development scholars acknowledge the necessity for water security and this study reinforces its importance to water resources management. However, much of the dedicated water security literature discusses broad policies while previous studies specific to domestic water demand have not considered how insecure water access can affect a population's consumption behavior.

The structure of this paper is as follows: Section 1 summarizes the literature of residential water demand estimation and studies of water insecurity. Section 2 examines the current geo-political situation of the West Bank as it pertains to water availability. The experimental design, survey data and statistical analysis are described in Section 3 and Section 4 provides the final results and discussion.

## Section 1. Price Elasticity and the Value of Domestic Water

### *Demand Estimation*

Many circumstantial factors, as detailed in Table 1., determine the water quantity a household can be expected to consume. Water demand is modeled with a multivariate demand function which allows calculation of each determinants' elasticity. Of the potential determinants, water suppliers typically control only one: price. Pricing elastic is thus extremely important to water supply management. It relates the costs of water units sold and the quantities a population can subsequently be expected to purchase relative to current consumption. Consumers typically use more resources as prices fall and less as they rise and price elasticity expresses the magnitude of that change. Estimates of price elasticity enable modeling realistic changes in water consumption under disparate circumstances, enabling water suppliers to balance supply and reimbursement needs.

Espey et al. (1997), Arbues et al. (2003), Worthington and Hoffman (2008) and House-Peters and Chang (2010) provide reviews of the domestic water demand literature. Arbues et al. (2003) and Kenney et al. (2008) summarize the common categories of explanatory variables included in previous multivariate domestic water demand functions. Arbues et al. (2003) also reviews the methods used to estimate demand elasticity from data in a multivariate regression.

Regression models make frequent use of aggregate community data (Dalhuisen et al., 2003), though Bell and Griffin (2011) caution that aggregate household demand data can be skewed when data sets also include commercial and industrial data. Hanke and de Mare (1982) recommend studies using micro level data based on interviews, such as their 1982 study in Malmo, Sweden, as well as studies like Jones and Morris (1984) in Denver, Colorado; Nieswiadomy and Molina (1989) in Denton; Texas, Schneider and Whitlatch (1991) in Columbus, Ohio; Arbues et al. (2000) in Zaragoza, Spain; Hajispyrou et al. (2002) in Cyprus and Al-Najjar et al. (2011) in Jordan. These studies, like the current study, require large amounts of information that can be challenging to collect accurately. Because consumers in the West Bank purchase water from multiple sources on the household level, it is not possible to gain a full picture of water demand from aggregate billing data, leaving surveys as the only option to collect realistic estimations.

Nuage and Thomas (2003) demonstrate that long-run price elasticity estimation can be more elastic, meaning more responsive to price changes, than short term estimation, and suggest this is due to slow reaction times. Hanke and de Mare (1982) advocate the use of time series data for studies of demand estimation (see Schneider and Whitlatch, 1991, Billings and Agthe, 1998). The current study, rather than attempting to model a continuous time series of water demand, focuses on two distinct times of water use in the West Bank, July-August and January-February, which respectively correspond to the time of peak and minimum water demand as determined through the survey. With a block rate tariff, both the quantity and the price are endogenous, making it difficult to simulate dynamic water demands within individual households. This problem is mitigated with use of the marginal price and difference variable.

Some researchers depend upon current water consumption and population growth statistics to predict future water demand (Panagopoulos et al., 2012, Bulene et al., 2013), while others investigate specific drivers of domestic water demand. The following table lists variables examined to date with example studies. Some listed variables have ambiguous relationships to water demand, 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 variable.

**Table 1. Potential Variables of Domestic Water Demand**

| Examined Variable | Example paper that examined it |
|---|---|
| ***Water Consumption (Q)*** | |
| Per capita domestic consumption | Almutaz et al. (2012), Mazzanti and Montini (2006), Bell and Griffin (2011) |
| Household consumption | Al-Najjar et al. (2011), Kenney et al. (2008), Dandy (1997) |
| Urban (residential and industrial/ commercial) consumption | Bell and Griffin (2011) |
| | |
| ***Billing*** | |
| Average price | Kenney et al. (2008), see list in Arbues et al. (2003), |
| Marginal price | Taylor (1975), see lists in Arbues et al. (2003) and Worthington and Hoffman (2008). See also Griffin et al. (1981) |
| Marginal price and difference variable | Nordin (1976), see lists in Arbues et al. (2003), and Worthington and Hoffman (2008) |
| Pricing structure | See Espey et al. (1997), Olmstead et al. (2003), see Arbues and Barberan (2009) for pricing structure explanations |
| Frequency of billing | Stevens et al. (1992) |
| Shin pricing | Shin (1985), Niesiadomy (1992) |
| Household knowledge of pricing | Gaudin (2006) |
| Water tariff not included in model | Almutaz et al. (2012) |
| Considering free allowances | Dandy et al. (1997) |
| | |
| ***Income or Income Indicators*** | |
| Household income | Salmon et al. (2008) |
| Per capita income | Mazzanti and Montini (2006) |
| Number of rooms | Grafton et al. (2011) |
| Number of bedrooms | Kenney et al. (2008) |
| Number of bathrooms | Salmon et al (2008) |
| Property value | Hewitt and Hanemann, (1995), Dandy et al. (1997), Arbues et al. (2003) |
| Plot size | Dandy et al. (1997) |

| | |
|---|---|
| Education level of head of household | Grafton et al. (2011), Jones and Morris (1984), Al-Najjar et al. (2011), Salmon et al (2008) |
| House ownership vs. renting | Espey et. al (1997), Kenny et al. (2008) |
| Have a telephone | Strand and Walker, (2005) |
| Number of cars | Bar-Shira et al. (2005), Jones and Morris, (1984), Mimi and Smith (2000) |
| Age of house | Kenney et al (2008) |
| | |
| ***Environmental*** | |
| Precipitation | Espey et al (1997), Maidment and Miaou (1986), Martinez-Espineira (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-Quanibet 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-Quanibet and Johnston (1985) |
| Windspeed | Al-Quanibet and Johnston (1985) |
| Thornthwaite's potential evapotranspiration | Dandy et al., (1997) |
| Ratio of warm and 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 Salmon et al. (2008), Schleicha and Hillenbrand, 2009, and 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 (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), Martinez-Espineira (2003), Mazzanti and Montini, (2006) |
| Age of respondent | Grafton et al. (2011), Kenney et al. (2008) |
| Type of house | Al-Najjar et al. (2011) see also Arbues et al. (2003) |
| Water delivery time | Strand and Walker (2005) |
| Type of water access | Strand and Walker, (2005) (dummy variables) |
| 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 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 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 | Schleich and Hillenbrand, 2009 |
| Home construction year | Nieswiadomy, 1992 |
| Indicator appliances (toilets, taps) | Al-Najjar et al. (2011), Mimi and Smith (2000) |
| Effects of delivery unreliability | Strand and Walker, 2005, current study. |
| | |
| ***Attitudes*** | |
| Environmental Concerns | Grafton et al. (2011), Domene and Sauri, 2005, Gilg and Barr 2006 |
| Participant in environmental groups | Grafton et al. (2011) |
| Leader in 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 bill cycle | Kenney et al. (2008) |
| Number of commercial enterprises in community | Mazzanti and Montini (2006), Musolesi and Nosvelli, 2007 |
| Maximum capacity city can supply | Nieswiadomy (1992) |
| Conservation campaigns in media | Agras et al. (1980), Renwick and Green (2000) see also Syme et al. (2000), Martin et al. (1984), Gegax et al. (1998). |

*The Cost of Water Insecurity*

For the purpose of this paper, resource insecurity is defined as the combination of consumers' resource vulnerability and lack of confidence that the entity controlling the resource is invested in the beneficiary's derived welfare. Versions of this dual component definition are also put forth by Zeitoun (2012) and Wutich and Ragdale (2008). Consumers can still have confidence in the water supply even if they understand it to be vulnerable, as in the southwestern United States. Feelings of insecurity thus stem in part from perception of the water governance due to past experiences and subsequently held beliefs.

Vulnerability is the first component of resource insecurity. Hashimoto et al. (1982) defines vulnerability as a measure of the likely consequence of system failure. The West Bank is vulnerable to water shortage because the region's natural aridity means there are few auxiliary sources if water becomes unavailable, thus delivery system failure has serious consequences for the people that depend upon it.

The second component of resource insecurity is an assumption about the influence an individual or a group can exert over the entity controlling its water.  Development scholars have long argued that problems in water supply are not only tied to scarcity, but to mismanagement in delivery. Leakages and ineffective cost recovery can diminish institutional capacity to delivery water (Meinzen-Dick and Appawamy, 2002, Srinivasan, 2010), creating unreliable water supplies for domestic users. As Zeitoun (2012) emphasizes, water access can be a commentary on who has power within a system and who does not. Unreliability can be one symptom of water insecurity because it shows the consumers do not have the influence to secure their access, especially if other users have reliable supply.

Beyond the physical consequences of health, hygiene and comfort, Ennis-McMillan (2001) also suggests that distress over water scarcity incorporates perceptions of authorities using water as a source of power, such that lack of water delivery becomes a social injustice.. Medical anthropology has defined health as “access to and *control over* the basic material and non-material resources that sustain and promote life” (Baer et al., 1997) [emphasis added]. Stevenson (2012) found water insecurity was “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 Scheper-Hughes, 1992 and Permenter, 2013).

The water allocation for the West Bank set forth in the Oslo Accords creates a situation where the Palestinian government cannot exercise full autonomy over its water resources. When the water comes infrequently, the reason is often unclear and consumers do not have a reliable method to address the problem. This can lead to feelings of powerlessness against an entity that is not consistently acting for the consumer’s benefit, especially coupled with a heightened awareness of power asymmetries between the Israeli and Palestinian governments and their resource access.

Inequity and injustice are major issues in the West Bank where Israeli settlements are highly visible to Palestinians and settler water consumption is thought to be six (Diabes, 2003, Koek, 2013) to nine (Freijat, 2003) times greater than their Palestinian neighbors. Control over water is also problematic: Rabbo (2010) suggests that Palestinians perceive Israel’s provision of water as another form of occupation and domination. Because settlers and Palestinians receive water through overlapping sources, the inequity in supply can reinforce Palestinians’ lack of confidence in their water supplier, fulfilling the second component of the water insecurity definition.

Unreliability is an important symptom of water insecurity and previous studies have investigated the role it plays in consumer experience. Water resources engineering often learns from energy utility studies, as in the case of Taylor's 1975 work on electricity demand. Current studies in electricity demand document user willingness to pay to avoid blackouts (Maliszewski et al., 2013, Carlsson and Martinsson, 2007, Carlsson and Martinsson, 2008, Abdullah and Mariel, 2010). This phenomenon demonstrates that risk imposes higher costs on the consumer. In the agricultural water sector, Calatrava Leyva and Garrido (2006) provide an excellent review of the costs of risk in water supply and Strzepek (2008) demonstrates that unreliable water supply can reduce agricultural system robustness.

Studies using the contingent valuation method have established user willingness to pay for improved domestic water reliability (Lund, 1995, Griffin and Mjelde, 1997, and Moffat et al., 2012). Moffat et al. (2012) and Griffin and Mjelde (1997) found correlations between willingness to pay for improved reliability and household income, though Meizen-Dick and Appasamy (2002) argue that the poor already pay the highest prices and have the most to gain. Around the world, the unconnected poor pay a huge premium for water access (Briscoe, 2009).

Strand and Walker (2005) examined the effects of intermittent supply in their water demand regression and found that rationed supply did not necessarily affect consumption due to sufficient storage coping strategies, which can negate service unreliability. However, they found 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.

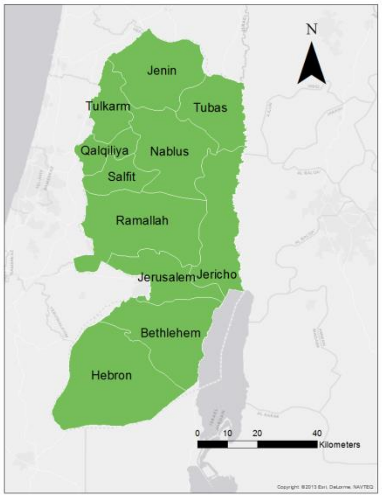
Metal and plastic tanks crowd the rooftops of Palestinian households in the West Bank. The tanks store water when the networks are empty or any additional water that has been purchased from tankers. Storage mitigates the effects of the discontinuous supply by ensuring access even in times without service. During the interviews, one household anecdotally described disconnecting from an unreliable network to buy from comparably priced tankers, consistent with Grey and Sadoff (2007) observations about risk aversion in securing water supply.

Because the literature confirms that delivery unreliability affects consumer willingness to pay and engenders water insecurity, analysis of demand elasticity should incorporate these factors as explanatory variables. Strand and Walker (2005) used dummy variables to characterize the time periods a household typically received water, with ambiguous results, but this study is the first to use subjective indicator scale to include water insecurity as a variable.

While unreliability can indicate water insecurity, it is not a prerequisite. During the study some interviewees referenced their unwillingness to stop using rooftop storage tanks, even when their water came continuously, due to their lingering uncertainty about future supply and overall lack of confidence in the water supplier. These responses helped develop this studies definition for water insecurity as vulnerability and a commentary on the relationship between the consumer and the supplier.

**Section 2. West Bank Domestic Water Demand**

**Figure 1. The West Bank**




The West Bank is the larger of the two Palestinian Territories, situated between Israel to the west and Jordan to the east. When the Ottoman Empire collapsed during World War I, what would become the West Bank fell under the sovereignty of the British Mandate, followed by Jordanian rule after 1948 and Israeli military occupation after 1967 (Smith, 2007).

It is important to recognize the complex history of the Palestinian – Israeli conflict when discussing the current water situation. It is not the aim of this paper to enumerate past injustices, but to fail to mention their existence would be a grave disservice to anyone committed to fully understanding the persistence of the conflict and its resulting impact on water demand. Smith (2007) provides one of many comprehensive histories.

*Palestinian Water Management*

The 1990s Oslo Accords that established the Palestinian Authority also formed the Palestinian Water Authority (PWA) to govern the region's water resources. However, Selby (2013) contends that the Oslo treaty has allowed Israel to maintain hegemony over the water resources of their weaker neighbors under the guise of cooperation. The World Bank published a brief history of Israeli methods for controlling the West Bank water supply, revealing systematic violations of the Oslo agreements and also addressing how the PWA has contributed to the water problem through internal mismanagement (World Bank, 2009).

Under the current water management regime, health and sanitation conditions are worsening in tandem with the massive deterioration of the environment (Palestinian Water Authority, 2012a). Estimates for Palestinian domestic water consumption are generally cited around 73 l/c/d, well below the World Health Organization recommended 100 l/c/d (cited in Kirke, 1984). Israeli consumption is around 300 l/c/d. See Appendix A for a list of citations.

Currently, the water supply for many West Bank residents does not reliably meet water demands without recurring shortages (Palestinian Water Authority, 2012a). To minimize the gap between supply and demand, in 2010, Palestinian water suppliers purchased 36% of the total supply from the Israeli company Mekorot, which in 2003 sourced 40% of its water from the West Bank aquifers (Daides, 2003) and today uses 85% of the total water available from West Bank aquifers (Palestinian Water Authority, 2012b), leaving only 15% for Palestinian use. Palestinian water abstraction has decreased since Oslo (World Bank, 2009) and Palestinian dependence on Mekorot supply increases each year (Palestinian Water Authority, 2012a) and Israel completely controls the pricing of this water (Palestinian Water Authority, 2012a, see also Hass, 2012).

For municipal water in the West Bank, dependence on Israel is higher, about 60% of the domestic water consumption (Tal and Rabbo, 2010). Compounding that, the majority of Palestinian-controlled water comes from wells but production is drying up in many regions (PWA 2012) and permission for Palestinians to drill deeper is difficult to obtain from Israel (World Bank, 2009, Selby 2013).

Improving Palestinian water access requires new infrastructure, maintenance of existing infrastructure, stronger institutions, utility cost recovery and adjustments in agreements with

Israel (PWA, 2012). International organizations have stated that the Israeli policies towards Palestinian water and sanitation constitute violations of international law (EWASH & Al Haq, 2011, UN Human Rights Committee, 2010, Selby, 2013 and see also Tignino, 2009). According to Glover and Hunter (2010), “While it is disingenuous to say that limitations in the Palestinian water sector are exclusively the result of Israeli policies, they are by far the primary determinant of Palestinian water insecurity.”

The Coase theorem states that ownership can be separated from benefit accruement in a cooperative system, provided that the various activities under consideration have values attached to them (Coase, 1960). Water availability in the West Bank is inherently tied to the Palestinian Authority’s asymmetrical relationship with Israel and water ownership is considered one of the five most intractable issues of the Palestinian-Israeli conflict (Allan, 1999). However, the Coase theorem allows optimization models, such as the model developed by Fisher et al. (2005), to reveal the potential benefits of different water use even in situations of contested ownership.

Moser’s vulnerability theory (Moser, 1998) states that people use a combination of social and economic assets to acquire sufficient access to a resource. In regions of water scarcity around the world, residents construct “water portfolios” of different water sources to decrease household susceptibility to water shortages (Stevenson, 2012, Mason, 2012, Moffat et. al, 2012). In Palestine, depending on existing infrastructure, water availability, quality and source reliability, families meet their needs by selecting from multiple water sources.

Srinivasan et al. (2010) argue that consumers are assumed to be rational and to have accurate information regarding the various costs of the water they choose to purchase, though Nieswiadomy and Molina (1989) have argued this is often not the case. Gaudin (2006) demonstrated that the knowledge of pricing can increase price elasticity, and Martin et al. (1984) suggests water pricing increases will only decrease consumption when accompanied by a major public awareness campaign. However, throughout the study it was observed that respondents reported water prices consistent with their community, their water bills and the PWA water pricing records, supporting Srinivasan's assumption.

*Palestinian Water Sources*

Domestic consumers have four major sources of water in the West Bank: cisterns, network water, tankers and bottled water. Users are expected to first purchase the lowest cost water and incrementally select higher and higher cost water based on their needs.

***Cisterns*** are large concrete containers, typically underground, designed to store water from various-sized catchments for later use. Though there are no known attempts to systematically enumerate cisterns in the West Bank, Zeitoun (2008) suggests rainwater is about 3% of total water consumption, including agricultural use. Cistern construction requires a large initial investment, but the benefits last for decades when properly maintained. The initial investment nearly covers the total cistern supply costs and this study made the assumption that cisterns function for fifty years, though this can be highly variable. Electricity for pumping costs was not accounted for, since it is also necessary for other types of supply. Cistern construction costs were interpolated and adjusted for inflation to 2012 values from 2008 PWA data (personal correspondence with Deeb Abdelghafour) and verified with prices reported in the surveys. Many interviewed families with cisterns used the water between March-June, outside the two periods examined, but for the remaining data, consistent assumptions had to be made about winter and summer distribution and the relationship between cistern capacity and yield in order to run the regression. This issue is addressed in Appendix B and C.

***Networked water*** varies spatially in price, pricing structure, quantity, quality, delivery schedule and source throughout the West Bank. As of 2010, reported water lost from network pipes varied between 22% (Salfit) and 40% (Tulkarem and Jerusalem), with an average of 29.4% across all the governorates (PWA, 2012). This water is either lost in leaky pipes or siphoned off illegally. The PWA literature reports that networks reach 96% of the West Bank population, but not all connected networks receive water in the pipes, decreasing the actual number of served communities. Furthermore, with the exception of communities connected to Israeli settlement water networks, all networks supply water in intervals that can be days, weeks or months apart, especially in the summer. Rooftop water tanks store water while the network is dormant.

***Tankers*** operate throughout the West Bank predominantly outside the control of any monitoring agency. The water can come from Palestinian wells or Israeli settlements (Zeitoun, 2008) and prices can be comparable to network water, as in Jenin, or much more expensive, as in Bethlehem. Palestinian pricing data in the literature is limited to Nasser (2003). Israeli military authorities can allow or prevent tanker operations, affecting reliability.

***Bottled Water*** can be purchased everywhere in the West Bank for prices greatly exceeding any of the other sources, but since it is meant for drinking water alone, the quantities are much smaller. Following the literature (Stand and Walker, 2005), bottled water is excluded from the analysis of domestic water because it provides such a small contribution to overall household use. Bottled water can be 500 to 1000 times more expensive than network water per cubic meter, but is typically bought in liters, which negligibly affect total household consumption values.

Discontinuous water supply entails various associated costs: infrastructure cost, monetary or opportunity cost of the space for the infrastructure, maintenance costs, and risk of bacterial contamination, among others. Furthermore, storage invariably introduces system inefficiencies by increasing opportunities for leaks, overflows and evaporation.

With the notable exception of the Palestinian Hydrology Group survey conducted before the Second Intifada (PHG, 2006), there is very little data available about household water practices in the West Bank (Glover and Hunter, 2010, World Bank, 2009). Though the water utilities have records for networked water, these have limited value without the knowledge of each family's supplemental consumption of cistern or tanker water. Lack of data is a primary challenge in any attempts to characterize the water situation in the West Bank.

## Section 3. The Survey of Household Water Demand

*Survey Design*

Guidance from the PWA framed the survey design and after testing and refining the questions in the summer of 2011, the survey received exemption status from the Institutional Review Board. All surveying took place during daytime home visits in the summer of the 2012. The PWA provided transportation, Arabic translators and demographic information for the communities targeted in the eleven West Bank political districts. Individual households were selected based on the presence of an adult at the time of visit. The survey (see Appendix D) included quantitative questions for data purposes and open ended questions to encourage discussion of more nuanced topics.

The survey recorded household demographics, including location, local governance, income bracket, number of household members, and children under five years of age.

Respondents detailed the price and purchased quantity of each water source, and the infrastructure they used to obtain and store water. Further questions examined accrued water debt and perceptions about billing accuracy and water quality, tactics for reusing water within the household and prompted recall (Wutich, 2009) of consumption differences between summer and winter. The survey also included a choice experiment to anticipate the household's response to various scenarios of water availability and pricing.

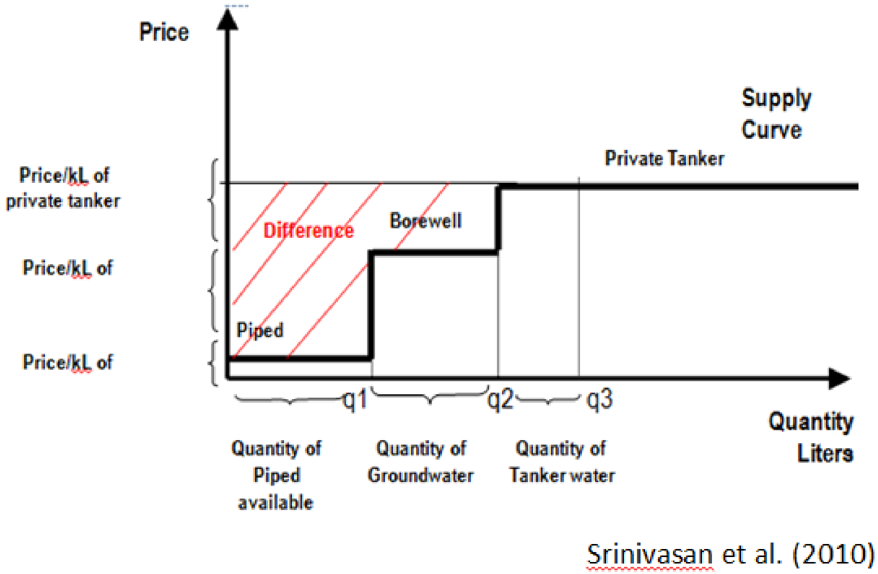
Surveys varied between 20-45 minutes each. Respondents were asked if they would like to participate and were not offered any type of reimbursement. Some respondents provided water bills to validate their answers, but many did not, and furthermore there is no existent monitoring data for cisterns or tankers. To counter the difficulty in estimating water consumption, surveys included redundancy in the questions to ensure that respondents provided consistent answers.

A total of 73 surveys were completed during the surveying period in 2012, revealing important details about tactics, coping mechanisms and struggles to obtain adequate water at the household level, but a subset of 64 surveys with summer data and 65 with winter data contain sufficient information for analysis. The surveyed households represent the spatial diversity of water experiences in the West Bank.

***Variable Selection***

Pricing under block rate structures, due to municipal rates or tailored water portfolios, has long divided scholars of demand elasticity (Arbues 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 the actual water bill and what the consumer would have paid if all the water had been billed at the last price of purchase, or the marginal price. Because the price of water is a step function, water use is a discrete continuous choice. The *difference* variable, shown in Figure 2., specifies the money saved by buying water from cheaper sources rather than the marginal price.

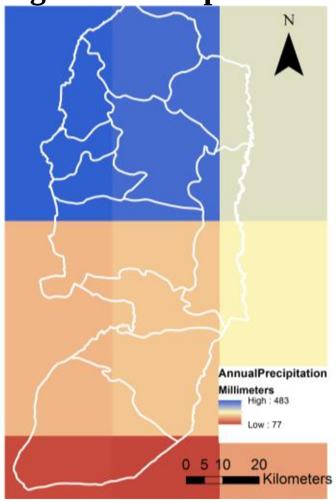
**Figure 2. The Difference Variable**




Household size was also included as an explanatory variable, as were environmental variables. This paper represents a departure from the literature by using Geographic Information Systems (GIS) to process satellite imagery characterizing the natural environments across the West Bank. GIS processed Aster, Landsat and MODIS satellite data as raster images which were subsequently analyzed using the *Zonal Statistics as Table* tool to find minimum, maximum, mean and median values for each raster data set.

For variables implicit in the community boundaries, like precipitation, surface temperature and elevation, all rasters were sampled within each community to generate local values. The precipitation raster was an average of annual precipitation from 1950-2000, provided by Comair et al., (2012). Since it does not rain during the summer, monthly values for precipitation were defined in the winter and set to zero for the summer.

**Figure 3. Precip. Raster**




A 1.5 kilometer buffer around each community was used for variables measuring the natural environment from cloudless winter and summer Landsat images from 1999 and 2000. These data sets are indexes using the following Landsat 7 bands.

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

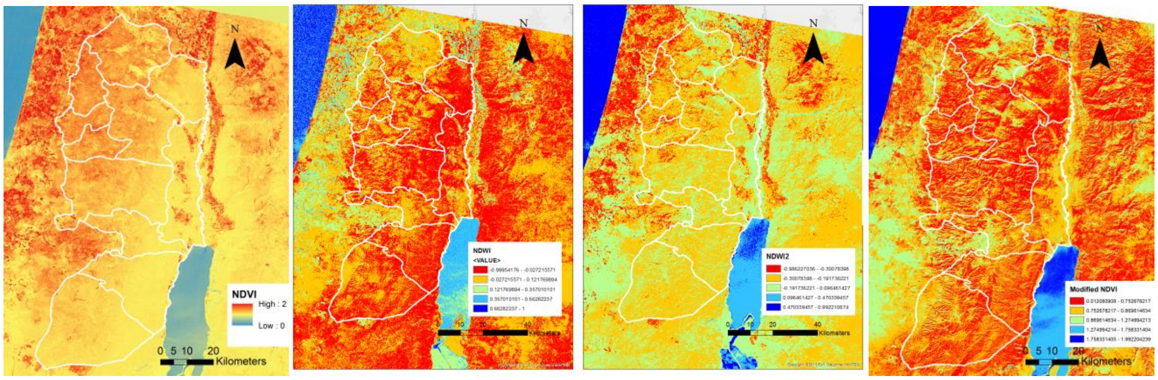
$$NDWI = \frac{1 - SWIR/NIR}{1 + SWIR/NIR}$$

$$NDWI2 = \frac{1 - NIR/Green}{1 + NIR/Green}$$

$$MNDWI = \frac{1 - SWIR/Green}{1 + SWIR/Green}$$

Where NIR = Near Infrared (band 4), Red = Red (band three), SWIR = Short Wave Infrared (band 5) and Green = Green (band 2). All band math operations were performed in ENVI. See Mather and Koch (2011).

**Figure 4. Rasters for NDVI, NDWI, NDWI2 and MNDWI, January 2000**




## Section 4. Results and Discussion

Using the survey data and GIS environmental data, a model can be constructed of relevant predictors for domestic water purchases. The regression model employed the following formulation

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

because the power log allows the parameter $\beta_n$ to be the direct expression of demand elasticity of the variable $X_n$. Using a step-function, income and number of children, land surface temperature and elevation were quickly discarded as predictors and natural logs of the variables were used for all explanatory variables except for D. The following table shows the model with the variable combination with the lowest p-values without consideration of insecurity.

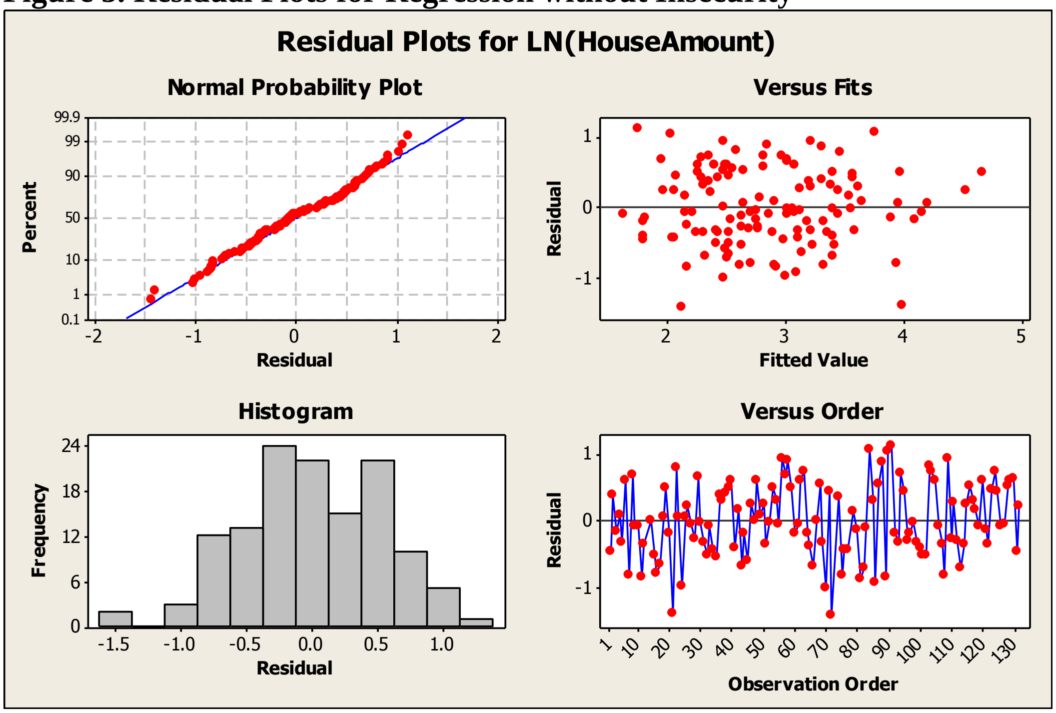
**Table 2. Minitab Regression Output – Insecurity Omitted**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value* (Calculated) | VIF |
|---|---|---|---|---|---|
| Constant | 2.7734 | 0.3161 | 8.77 | $9.326*10^{-15}$ | |
| LN(MarginalCost) | -0.10454 | 0.06574 | -1.59 | 0.114 | 1.338 |
| LN(HouseholdSize) | 0.67231 | 0.07958 | 8.45 | $5.552 \times 10^{-14}$ | 1.011 |
| D | 0.05388 | 0.01533 | 3.51 | $6.192 \times 10^{-4}$ | 1.239 |
| LN(MNDWImax) | 1.7359 | 0.3663 | 4.74 | $5.6 \times 10^{-6}$ | 2.696 |
| LN(NDVImax) | -2.3767 | 0.6788 | -3.50 | $6.408 \times 10^{-4}$ | 1.337 |
| LN(Precipitation Median) | -0.22147 | 0.02750 | -8.05 | $4.922 \times 10^{-13}$ | 2.657 |

**R-squared = 56.4%** **Adjusted R-squared = 54.2%** **Predicted R-squared = 51.53%**

*Values were calculated in Mathcad using 2 x (1-pt(T,n-1)) or 2 x pt(T,n-1) for negative T values.

**Figure 5. Residual Plots for Regression without Insecurity**




The following equation resulted.

$$Q = e^{2.77} * House^{0.67} * e^{.539D} * Cost^{-.104} * MNDWImax^{1.73} * PrecipitationMedian^{-.221} * NDVImax^{-2.38}$$

Where

*Q* = Cubic meters/household/month

*House* = Number of residents sharing supply

*D* = Per capita money savings of water bought at prices before the last price in New Israeli Shekels (NIS)

*MarginalCost* = Last price (which is not always the highest price) paid for water (NIS)

*MNDWImax* = Maximum MNDWI value for the 1.5 kilometer buffer around each city, excluding areas screened out for irrigation or other urban regions

*PrecipitationMedian* = Median precipitation value within each community

*NDVImax* = Maximum NDVI value in the 1.5 kilometer buffer around each city

This study deviates from many in the literature because income failed to play a role predicting the quantity of water households will purchase. This suggests consumption is independent of income, and the reason may be rooted in poverty and water scarcity. Average Palestinians spend about 8% of their income on water, twice the global average, and some households, and often the very poor, spend up to 45% (Glover and Hunter, 2010). Cairncross and Kinnear (1992) found in Khartoum that poor families paying between 17-56% of their income for water did not change their water consumption based on price, compensating instead by buying less food. The study concluded that the residents were subsisting at the bare minimum consumption level, explaining the lack of price elasticity and null income effect.

Additionally, in the current model, the p-value for price indicates price may not be an important variable, again speaking to the importance of a minimum water quantity. But this issue may also be a symptom of omitted variable bias.

Willingness to pay for water is tied to not only the price and the physical environment, but to reliability and capacity to control – to perceptions of water security. Determining factors for the value of water extend to consistency and timing of water delivery, and people's ability to anticipate their resource access as they strategize meeting their future needs.

Though an insecurity scale such as those used in Stevenson (2012), Hadley and Wutich (2009), and Hadley et al. (2007) was not part of the administered survey, the following subjective indicator scale and corresponding values was developed for use in the regression model. Each interview received a value corresponding to the household's water infrastructure at the time of reference (peak summer/non-peak winter).

**Table 3. Subjective Indicator Scale for Water Insecurity**

| | Least Insecure------------------------------------------------------------------------Most Insecure | | | | | |
|---|---|---|---|---|---|---|
| **Associated Costs** | Constant Supply – Cistern | Constant Supply – Network | Reliable Delivery – Network | Reliable Delivery – Tanker | Unreliable Network, supplemented by Tanker | Unreliable Network – Waiting for Water |
| **Storage infrastructure (maintenance, space, losses, contamination)** | Yes | Yes* | Yes | Yes | Yes | Yes |
| **Water payment, NIS/m3** | No | Yes | Yes | Yes | Yes | Yes |
| **Reliance on external players for water supply** | No | Yes | Yes | Yes | Yes | Yes |
| **Advanced Planning** | No | No | No | Yes | Yes | n/a |
| **Loss of control psychological distress** | No | No | No | No | No | Yes |
| **Associated Insecurity Score** | .1 | .2 | .4 | .5 | .6 | .8 |

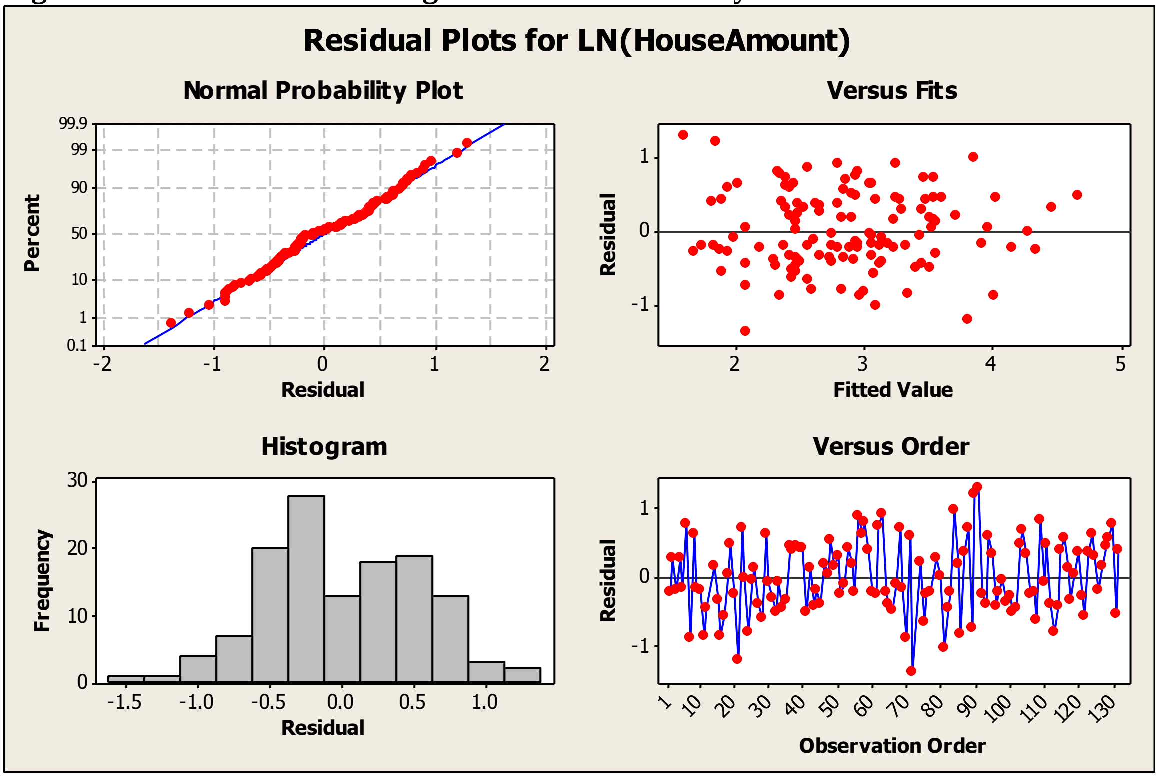
*A household with a constant network supply could be expected to dispense with its storage infrastructure. However, in the West Bank the families with constant water tend to be connected to Israeli settlement water supplies. Because that supply depends on another nation's caprices, interviewed households 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.

These values were subsequently included as an additional variable in the regression.

**Table 4. Minitab Regression Output – Insecurity Included**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value (Calculated) | |
|---|---|---|---|---|---|
| **Constant** | 3.3166 | 0.3573 | 9.28 | 0 | |
| **LN(MarginalCost)** | -0.27221 | 0.08531 | -3.19 | .002 | 2.395 |
| **LN(HouseholdSize)** | 0.67081 | 0.07717 | 8.69 | $1.465 \times 10^{-14}$ | 1.011 |
| **D** | 0.05535 | 0.01487 | 3.72 | $2.97 \times 10^{-4}$ | 1.241 |
| **LN(MNDWImax)** | 1.5658 | 0.3598 | 4.35 | $2.754 \times 10^{-5}$ | 2.767 |
| **LN(NDVImax)** | -2.0397 | 0.6680 | -3.05 | $2.782 \times 10^{-3}$ | 1.337 |
| **LN(Precipitation Median)** | -0.20101 | 0.02755 | -7.30 | $2.698 \times 10^{-11}$ | 2.836 |
| **LN(Insecurity)** | 0.3928 | 0.1328 | 2.96 | $3.666 \times 10^{-3}$ | 2.179 |
| **R-squared = 59.3%** | **Adjusted R-squared = 56.9%** | | | **Predictive R-squared = 54.18%** | |

**Figure 6. Residual Plots for Regression with Insecurity**




With the inclusion of water insecurity, there was a 260% increase in price elasticity from -0.104 to -0.272 due to omitted variable bias. Furthermore, the p-value for the price dropped from .114 to .002. Water insecurity plays a significant role in the regression by making the price variable relevant.

With all other factors – including price - held constant, higher water insecurity results in higher water consumption, suggesting that the situation of insecurity causes people to act inefficiently. This may due to storage losses or consumers' insufficient ability to strategize their consumption. For example, if the water comes and all the storage fills, the tasks subsequently performed in haste while the water still is running may not be performed efficiently. Additional water purchases could be made at more expensive prices because of bulk purchasing, as in the case of tankers. It is not known which of these options contributes more, or if there are other contributing factors. Further work should explore this.

The price elasticity determined in this model is -0.272 with a standard deviation of 0.085, giving a range of -.187 to -.357 with an adjusted $r^2$ of 56.9%. Appendix B shows the results of different cistern yield assumptions.

Appendix C shows another model developed using slightly different variables but still including insecurity and its sensitivity analysis. This model shows a price elasticity of -.395 and a standard deviation of .100, giving an elasticity range of -.295 to -.495 with an adjusted $r^2$ of 56.3%. This alternative regression model includes data for households that did not pay for their water, although in both cases a system in place ensured their water was otherwise paid for, complicating how to include the data. The higher elasticity of this regression model reflects the greater room for flexibility perhaps because some households paid nothing.

The only previous known study of domestic water demand in the West Bank found consumers in Ramallah to have price elasticity of -.6, higher than the results of this study but still relatively inelastic. (Mimi and Smith, 2000).

The following table compares values for domestic water demand price elasticity using similar pricing variables.

**Figure 7. Previous Elasticity Estimations**

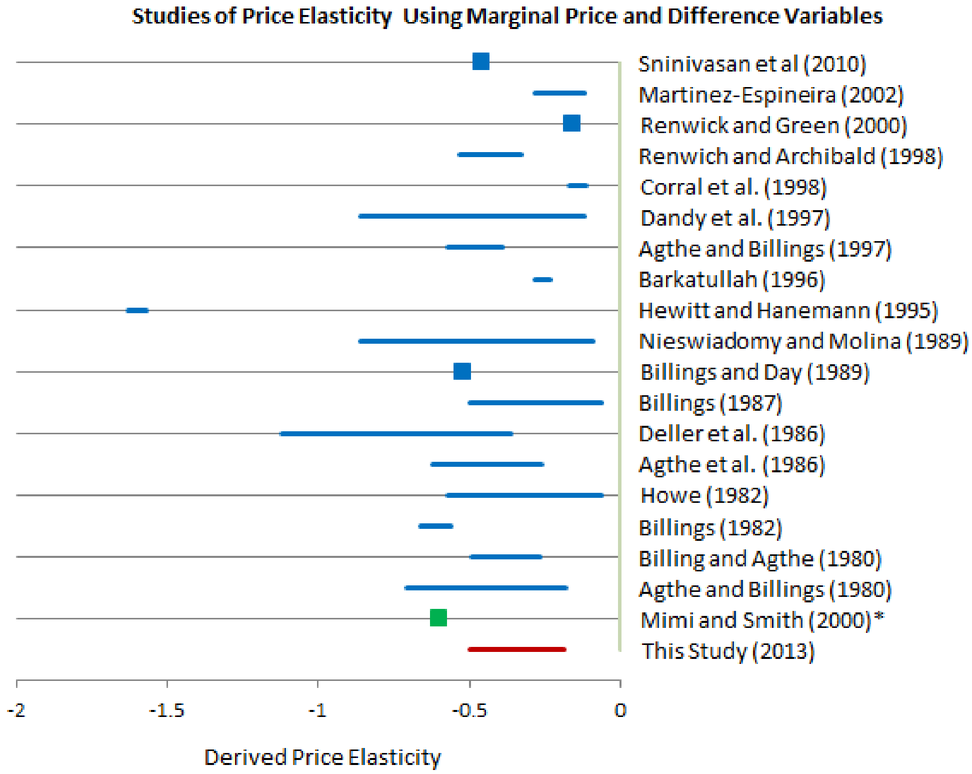



Figure 7. shows a review of 19 previous studies of domestic water consumption and their values for price elasticity. All these studies used the same method for pricing variables as this study: marginal price and *difference* variable, with the exception of Mimi and Smith (2000) which was included because it is the only other known study of Palestinian price elasticity.

The full implications of water insecurity in the regression model require further study. The Palestinian experience with water insecurity is not a problem limited to the poor. It pervades households everywhere based on location, season, and local governance and resources. Currently households respond to the dual problem of scarcity and water insecurity by storing water when it comes, consistent with the findings of Cairncross and Kinnear (1992) in Khartoum.

Gaudin (2006) and Salmon et al. (2008) suggest that when price elasticity is low enough, priced-based policies cannot serve as a conservation tool for municipal water. The analysis of water insecurity suggests that policy makers can still influence water consumption through non-price measures such as controlling reliability. As stated earlier, reliable water has more value and additional reliability may increase perceptions of water security.

The notion of higher water use due to insecurity contrasts with the more intuitive and widespread assumption that water rationing due to scarcity results in constrained water consumption. However, the West Bank is not strictly a rationing situation, due to irregular water delivery and those who can afford it can buy tanker water. Inadequate storage or insufficient total delivery, however, can become symptoms of water insecurity, implying that there may be a threshold when water rationing becomes unreliable enough to engender water insecurity.

Stated from a perspective of psychological consequences, should a population anywhere be denied lack of control over a resource, there might be a threshold beyond which price, like income, ceases to play a role.  Anecdotally, a lack of sense of control seems to beget a lack of sense of responsibility. Uncertainty in water delivery suggests conditions of *learned helplessness* (Seligman and Maier, 1967) to explain the declining value of unreliable water. This may link the opposing ideas of lowered consumption under rationing and inefficient use under insecurity, thought the relationship requires further research.

Storage of any resource imposes social costs by compounding scarcity and impeding other people's ability to freely access materials (Weitzman, 1991). Price elasticities with a value less than one are considered inelastic: consumption will not greatly change with price changes, so there is reason to assume consumption will also stay relatively steady if the same amount of water is delivered reliably. Such a change is political and independent of resources, but holds the power to benefit many people. A predictable system allows its users to plan their consumption efficiently.

Governance can address water insecurity, an issue the UN is currently studying (UN-Water, 2013). As has perhaps been demonstrated in this paper, the issue is inherently multi-disciplinary, with ramifications for water management in every field involved. Water security is an essential component of human security, and in the developing world addressing water security can contribute to long term stability (UN-Water, 2013). Policy makers struggle to reconcile water supply and demand, and demand side management options have long been considered limited to price control and conservation education. However, the regression suggests that addressing water insecurity can have long term implications for population consumption behavior.

There are many weaknesses in this study: the survey size was small and the sampling method likely led to selection bias of interviewees by overemphasizing vulnerable populations. Much of the data came from self-reporting, often concerning quantities and prices that cannot be cross-referenced. The cistern data is not well documented and required several assumptions which are stated throughout the paper. A sensitivity analysis is provided in Appendix B and C. The environmental satellite data is dated and, with the exception of precipitation, consists of snapshots in time rather than monthly averages that might be more informative. Screening for negative impacts of irrigation was not entirely effective, and Jericho Landsat data had to be substituted with Al Malih data from further north in the Jordan Valley. However, the use of satellite imagery has allowed this study to include variables that were not otherwise available.

### ***Conclusion***

This study is the first to examine the influence of water insecurity on the demand and price of domestic water, and findings suggest that improving service predictability, even without changing the quantity, allows consumers to exercise control over their consumption. In absence of that, the consequences of water insecurity include redundancy, inefficiency, and human suffering (Ennis-McMillan, 2001, Wuttich and Ragsdale, 2008). UN Water (2013) provides broad recommendations to encourage water security and Zeitoun (2011) warns not to exclude the social aspects of water scarcity and insecurity, including equity issues, from the policy discussion. For Israel-Palestine, this will entail convincing both sides that Israel benefits from relinquishing more water and autonomy over water to the Palestinians. The MYWAS model can facilitate this process by explicitly demonstrating how cooperation generates mutual benefits. Once the model is complete, it will readily address the concomitant problems of water scarcity and insecurity.

Policy-makers have many options to improve the benefits of water in scarce regions. Pricing policies remain an effective tool, and conservation campaigns are carried out across the Middle East, but this study suggests that improving water supply reliability and consumer confidence can be additional tools of policy intervention to affect consumer behavior. Further study will be necessary to clarify the precise mechanisms that cause insecure households to buy more water. Meanwhile the current water situation in the West Bank is dire and future climate change will only exacerbated it.  Decision makers have the opportunity to understand consumer perspectives and to implement beneficial policies for the people dependent on them for water.

*Appendix A.*

**Table 5. Estimates for Domestic Water Consumption in Israel[1] and the West Bank**

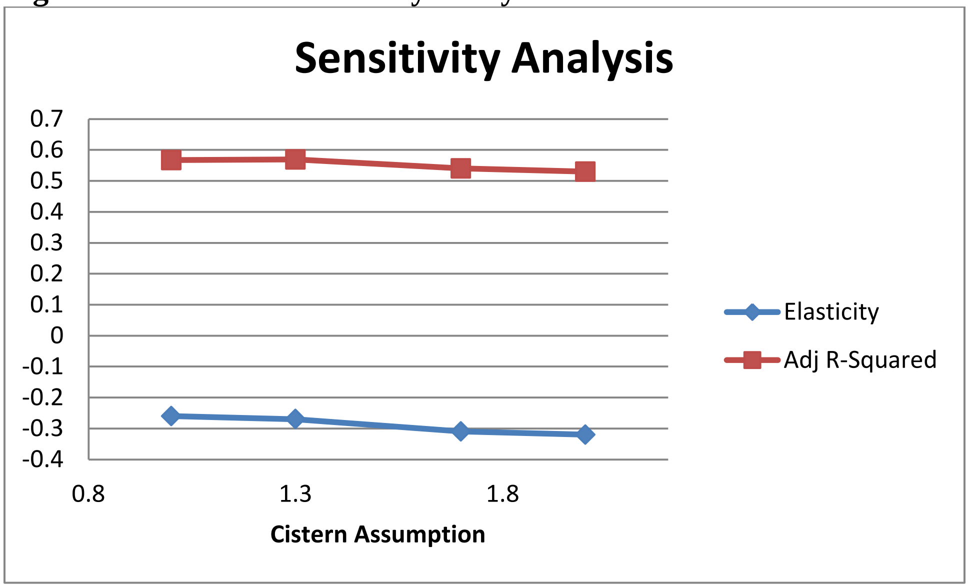
| Source | Description | Israel | The West Bank |
|---|---|---|---|
| **Nasser (2003)** | Domestic Supply | 250 l/c/d | 77.3 l/c/d |
| **Daibes (2003)** | Domestic consumption | Over 300 l/c/d | 35-80 l/c/d |
| **Jayyousi (2003)** | Municipal water needs/ Domestic consumption | 105 cmc/capita/year (288 l/c/d) | 60 l/c/d |
| **Fischer (2006)** | Per capita domestic water use | 100 cmc/capita/year (274 l/c/d) | 30cmc/capita/year (82.1 l/c/d) |
| **Zeitoun (2008): 14** | Fresh water resources | 240-300 l/c/d | 30-100 l/c/d |
| **Salmon et al. (2008)** | Domestic consumption | 280 l/c/d | |
| **World Bank (2009): 14** | Household | | 50 l/c/d |
| **Glover and Hunter (2010): 14** | Household | | 60.5 l/c/d |
| **Aliewi (2010): 18** | Household | | 50 l/c/d |
| **PWA (2010): 9** | Household | 300 l/c/d | 73 l/c/d |
| **Fixler (2010) as cited in Bullene et al. (2013)** | Domestic | 104.67 (9.33 s.d.) MCM/year (261-312 l/c/d) | |
| **Fixler (2011)** | Estimated domestic demand for 2011 | 89 MCM/year (243.8 l/c/d) | |
| **Netanyahu (2011)** | Daily domestic consumption | 250 l/c/d | |
| **B'tselem (2013)** | Urban, domestic and industrial use | 211-242 l/c/d | 73 l/c/d |

[1] This data concerns Israelis living in Israel, not the West Bank – data on Israeli settlement water use is not available.

*Appendix B. Sensitivity Analysis*

The model formulation presented in this paper was developed with the assumption that all cisterns yielded 1.3 times the amount of their reported maximum water storage. The following graph shows the changes in the adjusted r-squared values and the price elasticity between the assumptions cistern yield of 1 or 2 times the largest amount of stored water reported.

**Figure 8. Values for Sensitivity Analysis**




The adjusted r-squared values decrease slightly with increased cistern yield assumptions, and the elasticity increases. The lack of reliable cistern data is a weakness of this study, and until the storage yield relationship is better understood, either independently or generally across the West Bank, it is important to recognize how the assumptions made for the regression model effect the derived values.

Furthermore, the Minitab output tables from the cistern sensitivity analysis are shown below. As the cistern assumptions increase, so do the p-values for two of the three environmental factors (NDVI and MNDWI) as well as the water insecurity variable.

**Table 6. Assumption of Yield Equal to Reported Maximum Storage**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.1941 | 0.3437 | 9.29 | 0 | 0 |
| LN(Cost) | -0.26180 | 0.08269 | -3.17 | .002 | $9.538 \times 10^{-4}$ |
| LN(House) | 0.66821 | 0.07688 | 8.69 | 0 | $7.327 \times 10^{-15}$ |
| D | 0.05413 | 0.01463 | 3.70 | 0 | $1.595 \times 10^{-4}$ |
| LN(MNDWImax) | 1.5461 | 0.3586 | 4.31 | 0 | $1.614 \times 10^{-5}$ |
| LN(NDVImax) | -1.8539 | 0.6701 | -2.77 | .007 | $3.22 \times 10^{-3}$ |
| LN(Precipitation Median) | -0.19539 | 0.02762 | -7.07 | 0 | $4.477 \times 10^{-11}$ |
| LN(Insecurity | 0.3708 | 0.1285 | 2.89 | .005 | $2.263 \times 10^{-3}$ |
| R-squared = 59.1% | | Adjusted R-squared = 56.7% | | | |

**Figure 9. Residual Plots for Regression with Yield Equal to Reported Maximum Capacity**

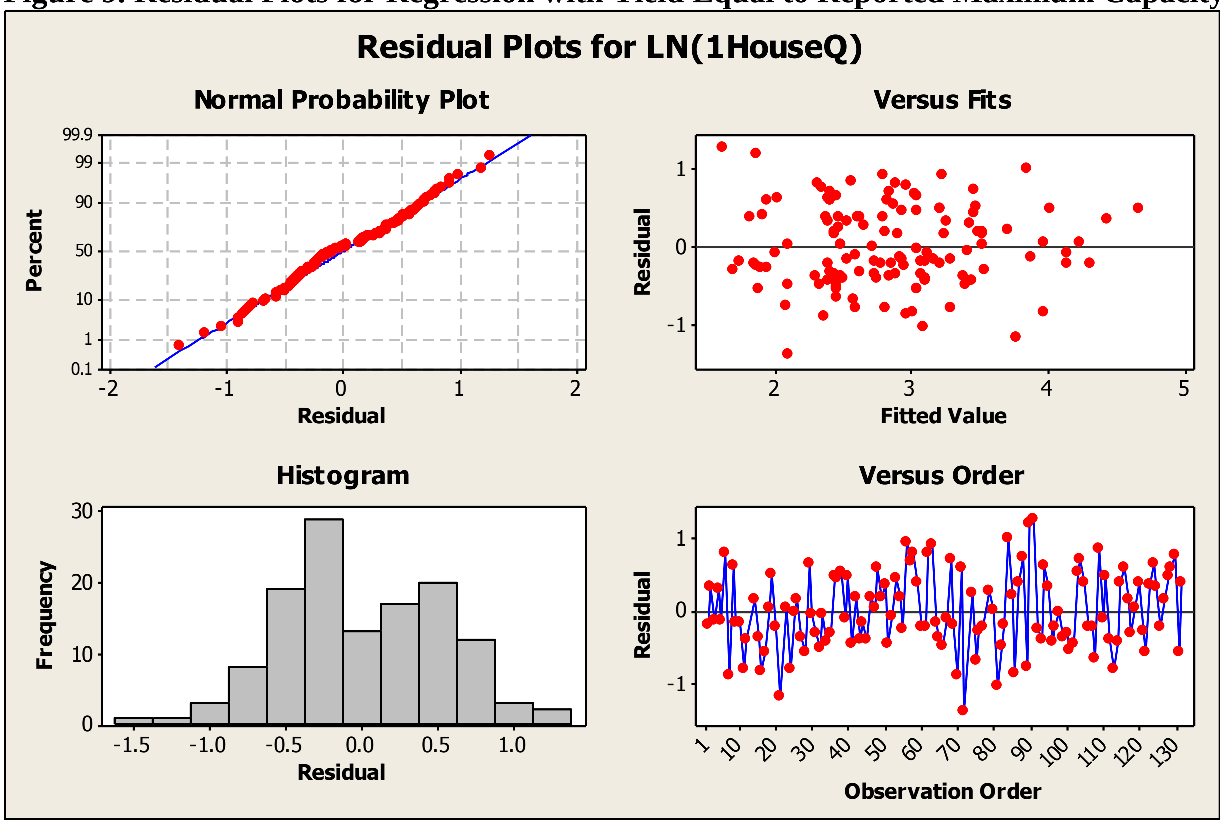


**Table 7. Assumption of Yield Equal to 1.7x Amount Reported Maximum Storage**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.2262 | 0.3280 | 9.55 | 0 | 0 |
| LN(Cost) | -0.31005 | 0.07550 | -4.11 | 0 | $3.51 \times 10^{-5}$ |
| LN(House) | 0.64682 | 0.07605 | 8.51 | 0 | $1.998 \times 10^{-14}$ |
| D | 0.05694 | 0.01437 | 3.96 | 0 | $6.184 \times 10^{-5}$ |
| LN(MNDWImax) | 1.2098 | 0.3472 | 3.48 | .001 | $3.431 \times 10^{-4}$ |
| LN(NDVImax) | -1.7534 | 0.6611 | -2.65 | .009 | $4.532 \times 10^{-3}$ |
| LN(Precipitation Median) | -0.17948 | 0.02705 | -6.63 | 0 | $4.264 \times 10^{-10}$ |
| LN(Insecurity | 0.2863 | 0.1333 | 2.15 | .034 | 0.017 |
| R-squared = 56.5% | | Adjusted R-squared = 54.0% | | | |

**Figure 10. Residual Plots for Regression with Yield Equal to 1.7x Reported Maximum Capacity**

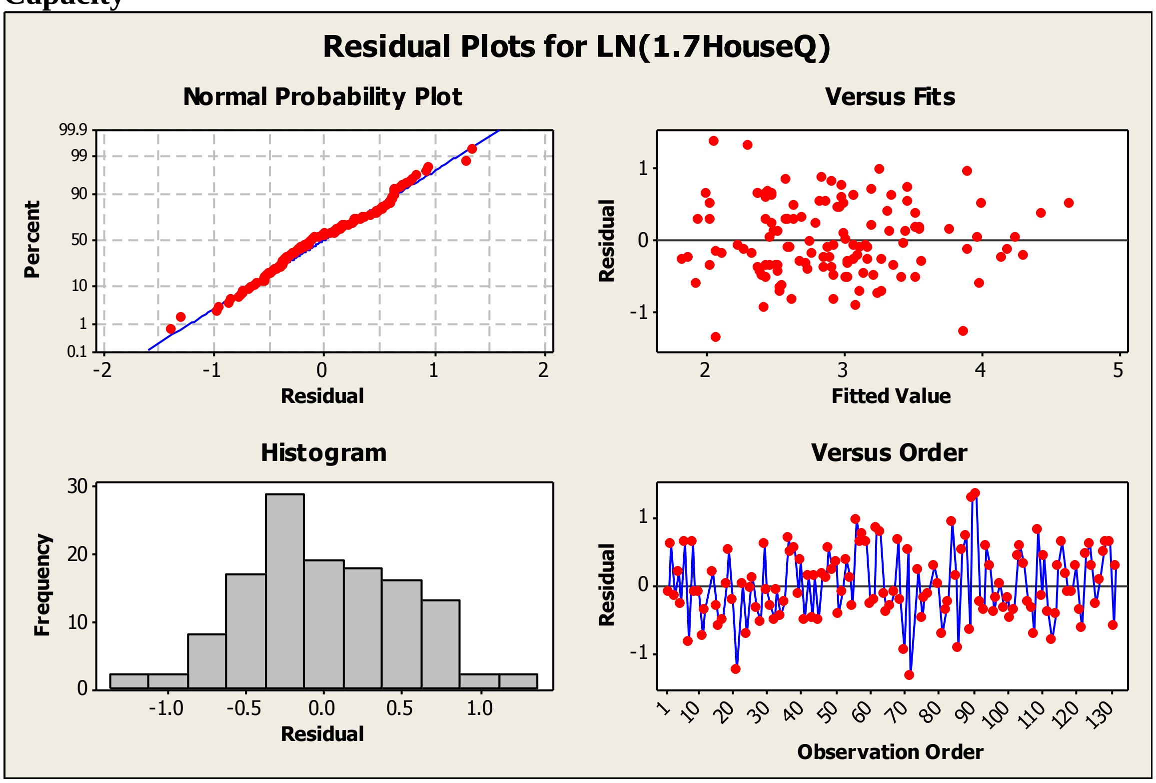
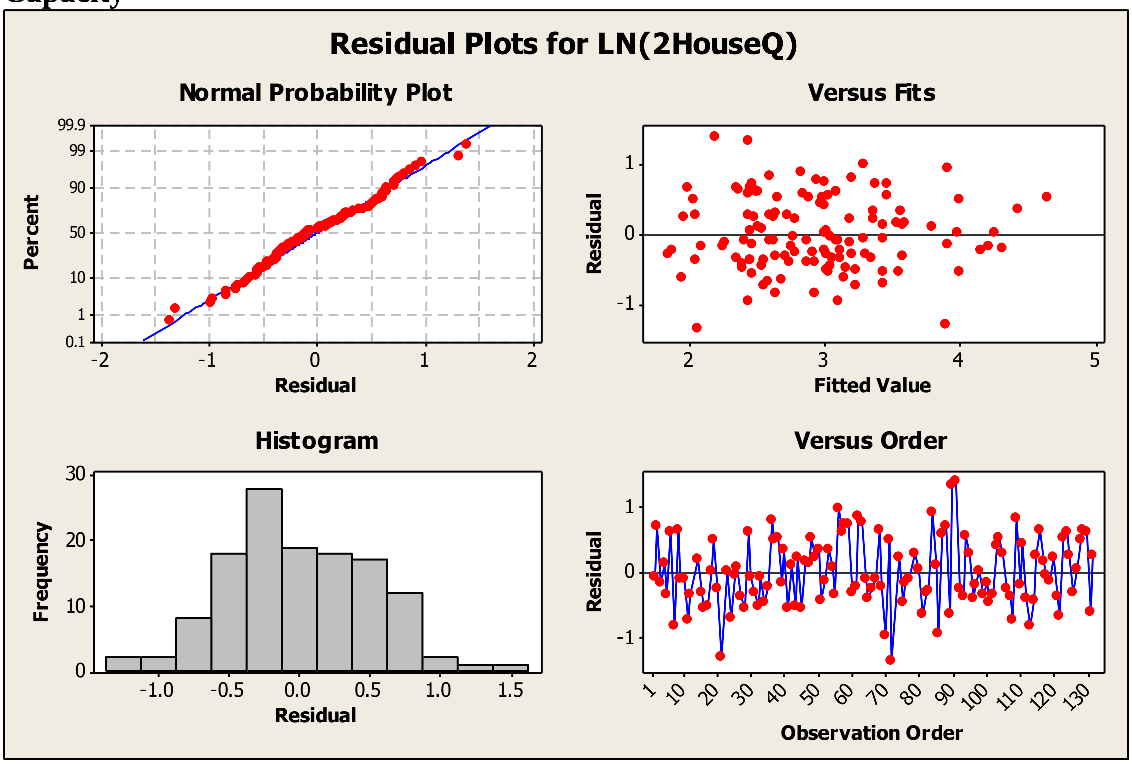


Table 8. Assumption of Yield Equal to 2x Amount Reported Maximum Storage

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.2515 | 0.3384 | 9.61 | 0 | 0 |
| LN(Cost) | -0.32954 | 0.07374 | -4.47 | 0 | $8.516 \times 10^{-6}$ |
| LN(House) | 0.64160 | 0.07637 | 8.40 | 0 | $3.642 \times 10^{-14}$ |
| D | 0.05792 | 0.01439 | 4.02 | 0 | $4.939 \times 10^{-5}$ |
| LN(MNDWImax) | 1.1096 | 0.3471 | 3.20 | 0.002 | $8.665 \times 10^{-4}$ |
| LN(NDVImax) | -1.7204 | 0.6633 | -2.59 | .011 | $5.355 \times 10^{-3}$ |
| LN(Precipitation Median) | -0.17488 | 0.02711 | -6.45 | 0 | $1.046 \times 10^{-9}$ |
| LN(Insecurity) | 0.2711 | 0.1354 | 2.00 | 0.048 | 0.024 |
| R-squared = 55.9% | | Adjusted R-squared = 53.3% | | | |

Figure 11. Residual Plots for Regression with Yield Equal to 2x Reported Maximum Capacity



## *Appendix C. Alternative Regression Model*

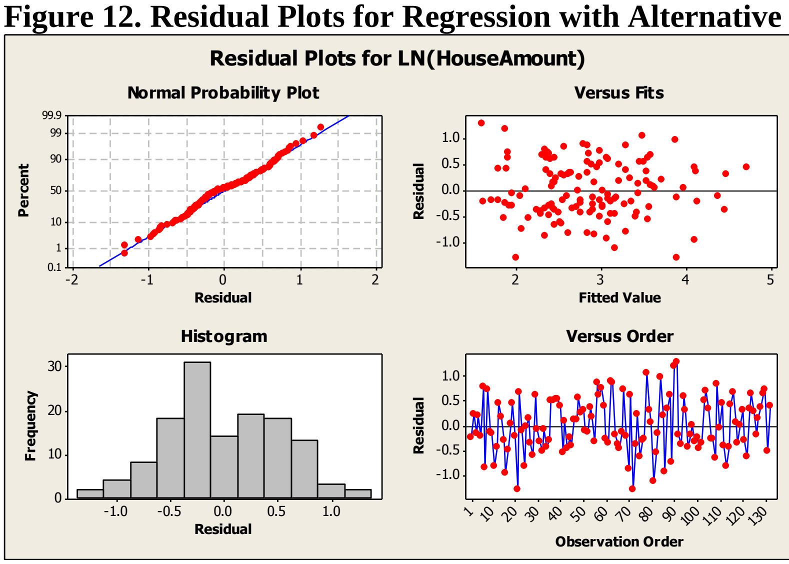
The regression model in the paper used the natural logarithm of the unit water price. Because there were three data families that did not pay for their water due to alternative arrangements (non-resident paying, refugee camp), these were excluded because of the need to take natural logarithms and also because it was not clear how to address these situation.

This section considers the data with these additional points, which were kept in the model by adding a constant when taking the natural logarithm. Using the same variables from the model derived in the paper, there is a slightly better adjusted r-squared, and the elasticity is significantly higher, as in the value of standard deviation.

**Table 9. Regression with Alternative Price**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.5134 | 0.3845 | 9.14 | 0 | 0 |
| LN(Price2) | -0.4075 | 0.09824 | -4.15 | 0 | $2.973 \times 10^{-5}$ |
| LNHouse | 0.71709 | 0.07495 | 9.57 | 0 | 0 |
| D | 0.05764 | 0.01507 | 3.82 | 0 | $1.026 \times 10^{-4}$ |
| LN(MNDWImax) | 1.4431 | 0.3544 | 4.07 | 0 | $4.04 \times 10^{-5}$ |
| LN(NDVImax) | -1.9359 | 0.6639 | -2.92 | 0.004 | $2.061 \times 10^{-3}$ |
| LN(PrecipitationMedian) | -0.19637 | 0.02729 | -7.19 | 0 | $2.216 \times 10^{-11}$ |
| LN(Uncertainty) | 0.4035 | 0.1252 | 3.22 | 0.002 | $8.083 \times 10^{-4}$ |
| R-Sq = 60.4% | | R-Sq(adj) = 58.1% | | | |

**Figure 12. Residual Plots for Regression with Alternative Price**

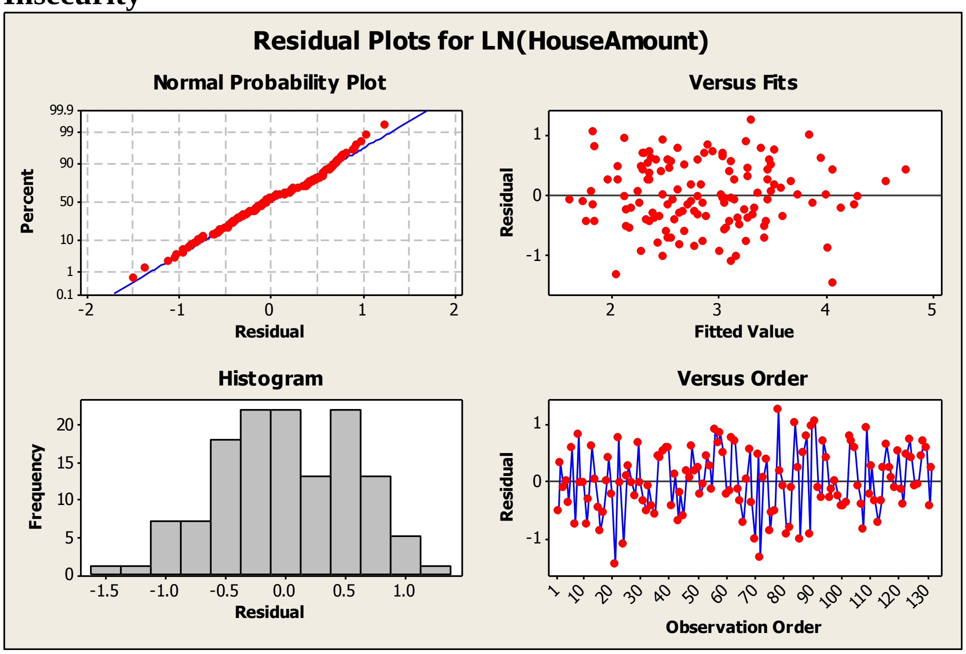


Similarly to the regression in the paper, the price elasticity varies greatly with the inclusion or exclusion of the water insecurity variable. The table below shows the regression with the alternative price and without water insecurity.

**Table 10. Regression with Alternative Price, Excluding Water Insecurity**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 2.8673 | 0.3402 | 8.43 | 0 | $2.72 \times 10^{-14}$ |
| LN(Price2) | -0.21614 | 0.08117 | -2.66 | 0.009 | $4.395 \times 10^{-3}$ |
| LNHouse | 0.71292 | 0.07771 | 9.17 | 0 | 0 |
| D | 0.05714 | 0.01563 | 3.66 | 0 | $1.823 \times 10^{-4}$ |
| LN(MNDWImax) | 1.5599 | 0.3656 | 4.27 | 0 | $1.863 \times 10^{-5}$ |
| LN(NDVImax) | -2.215 | 0.6825 | -3.25 | 0.002 | $7.334 \times 10^{-4}$ |
| LN(PrecipitationMedian) | -0.21385 | 0.02774 | -7.71 | 0 | $1.393 \times 10^{-12}$ |
| R-Sq = 57.1% | | R-Sq(adj) = 55.0% | | | |

**Figure 13. Residual Plots for Regression with Alternative Price, Excluding Water Insecurity**

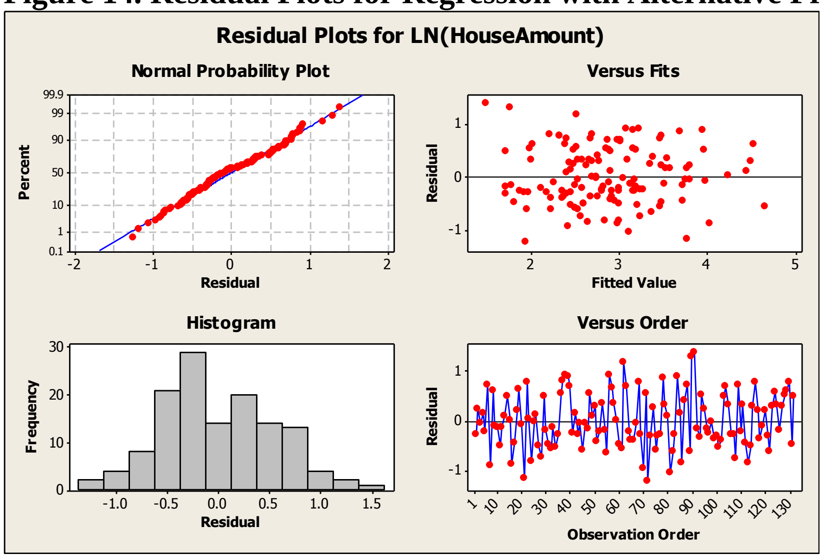



In the process of examining the price variable, an alternative regression model was developed. It replaces the NDVI and MNDWI variables with the single NDWI2 variable for roughly the same fit. The price elasticity remains more elastic with this price than the price used in the original model. This is to be expected since there is more room for change when the customer pays nothing.

**Table 11. Assumption of Yield Equal to 1.3x Reported Maximum Storage, Using the Alternative Price**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.0571 | 0.3236 | 9.45 | 0 | 0 |
| LN(Price2) | -0.395 | 0.1003 | -3.94 | 0 | $6.592 \times 10^{-5}$ |
| LNHouse | 0.69689 | 0.07633 | 9.13 | 0 | 0 |
| D | 0.05 | 0.01525 | 3.28 | 0.001 | $6.65 \times 10^{-4}$ |
| LN(NDWI2max) | 2.2874 | 0.6787 | 3.37 | 0.001 | $4.939 \times 10^{-4}$ |
| LN(PrecipitationMedian) | -0.18577 | 0.02939 | -6.32 | 0 | $1.891 \times 10^{-9}$ |
| LN(Uncertainty) | 0.3937 | 0.1287 | 3.06 | 0.003 | $1.343 \times 10^{-3}$ |
| R-Sq = 58.3% | | R-Sq(adj) = 56.3% | | | |

**Figure 14. Residual Plots for Regression with Alternative Price, 1.3x Cistern Assumption**

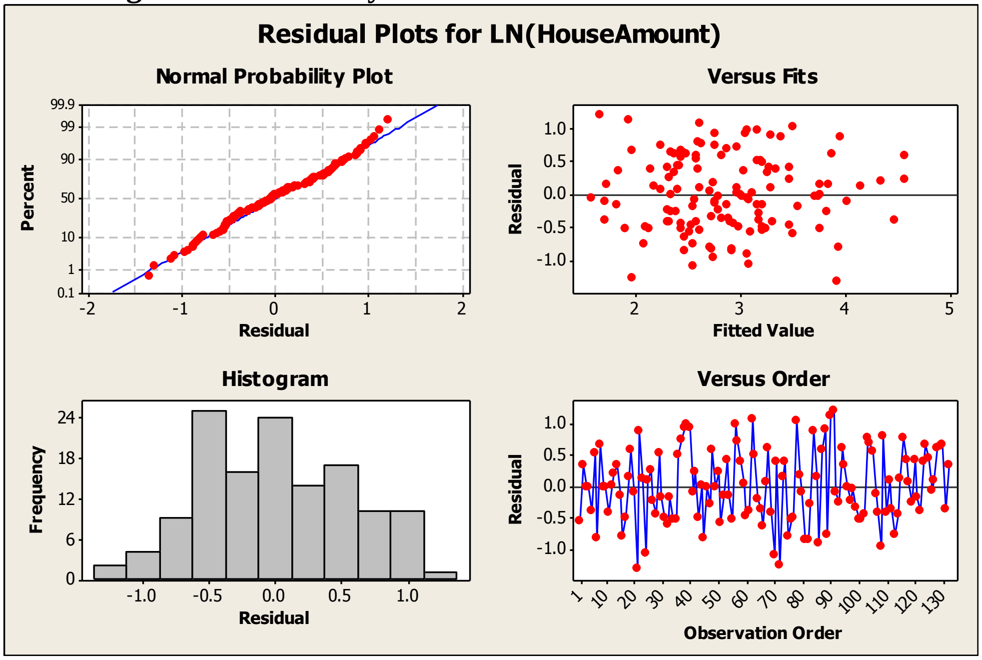



The water insecurity variable proves to still affect the price variable in the alternative model.

**Table 12. Assumption of Yield Equal to 1.3x Amount Reported Maximum Storage, Using the Alternative Price, Excluding Water Insecurity**

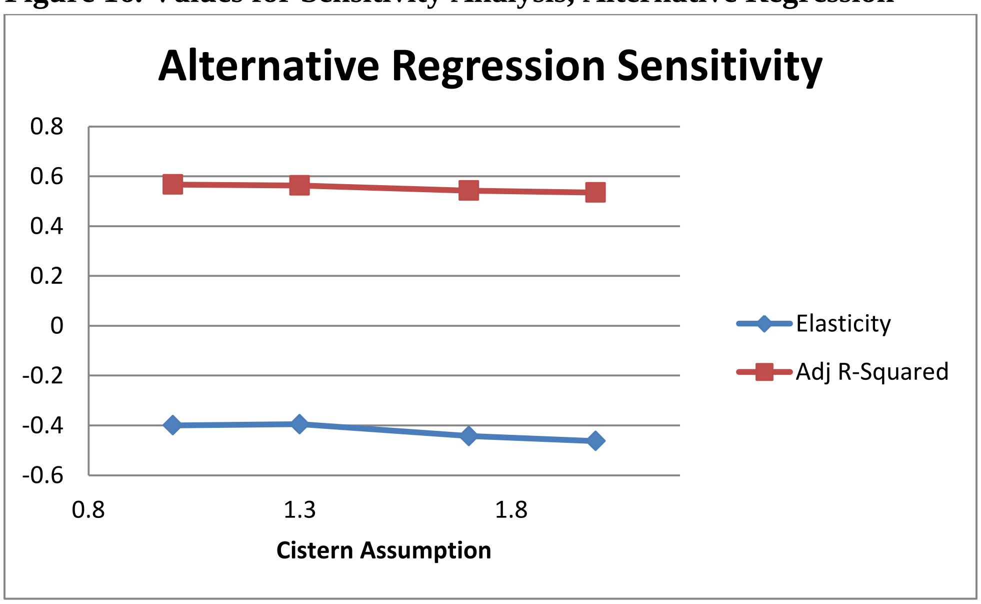
| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 2.363 | 0.2383 | 9.91 | 0 | 0 |
| LN(Price2) | -0.20199 | 0.08051 | -2.51 | 0.013 | $6.646 \times 10^{-3}$ |
| LNHouse | 0.6905 | 0.0788 | 8.76 | 0 | $4.33 \times 10^{-15}$ |
| D | 0.04807 | 0.01573 | 3.06 | 0.003 | $1.343 \times 10^{-3}$ |
| LN(NDWI2max) | 2.6592 | 0.6895 | 3.86 | 0 | $8.864 \times 10^{-5}$ |
| LN(RealPrecMedian) | -0.20753 | 0.02945 | -7.05 | 0 | $4.609 \times 10^{-11}$ |
| R-Sq = 55.2% | | R-Sq(adj) = 53.4% | | | |

**Figure 15. Residual Plots for Regression with Alternative Price, 1.3x Cistern Assumption, Excluding Water Insecurity**




The graph below shows the results of the sensitivity analysis conducted using this alternative regression. As with the previous sensitivity analysis, the r-squared value decreases with increasing cistern yield assumptions while the elasticity increases.

**Figure 16. Values for Sensitivity Analysis, Alternative Regression**



The tables for the various cistern assumptions under the alternative regression model are below. Like the original regression model, the *p-value* for the environmental factor, NDWI2 and the water insecurity become higher as the cistern yield assumption increases.

**Table 13. Assumption of Yield Equal to 1x Amount Reported Maximum Storage, Using the Alternative Price**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.0259 | 0.3113 | 9.72 | 0 | 0 |
| LN(1Price2) | -0.3998 | 0.09733 | -4.11 | 0 | $3.467 \times 10^{-5}$ |
| LNHouse | 0.69614 | 0.07555 | 9.21 | 0 | 0 |
| 1D | 0.04989 | 0.01495 | 3.34 | 0.001 | $5.458 \times 10^{-4}$ |
| LN(NDWI2max) | 2.316 | 0.6684 | 3.47 | 0.001 | $3.526 \times 10^{-4}$ |
| LN(RealPrecMedian) | -0.18328 | 0.02911 | -6.3 | 0 | $2.088 \times 10^{-9}$ |
| LN(Uncertainty) | 0.3762 | 0.1237 | 3.04 | 0.003 | $1.429 \times 10^{-3}$ |
| R-Sq = 58.7% | | R-Sq(adj) = 56.7% | | | |

**Figure 17. Residual Plots for Regression with Alternative Price, 1x Cistern Assumption**

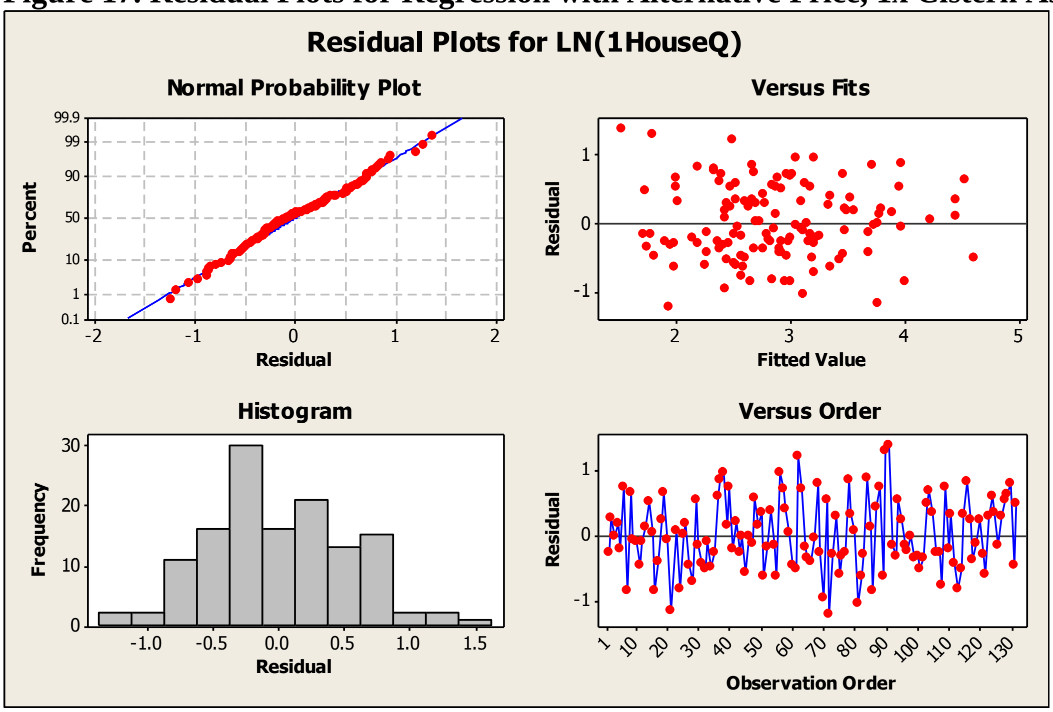


**Table 14. Assumption of Yield Equal to 1.7x Amount Reported Maximum Storage, using the Alternative Price**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.0224 | 0.3097 | 9.76 | 0 | 0 |
| LN(1.7Price2) | -0.44394 | 0.0942 | -4.71 | 0 | $3.114 \times 10^{-6}$ |
| LNHouse | 0.66679 | 0.07454 | 8.95 | 0 | $1.554 \times 10^{-15}$ |
| 1.7D | 0.05334 | 0.0147 | 3.63 | 0 | $2.026 \times 10^{-4}$ |
| LN(NDWI2max) | 1.6155 | 0.654 | 2.47 | 0.015 | $7.399 \times 10^{-3}$ |
| LN(RealPrecMedian) | -0.16166 | 0.02862 | -5.65 | 0 | $4.78 \times 10^{-8}$ |
| LN(Uncertainty) | 0.2703 | 0.1261 | 2.14 | 0.034 | 0.017 |
| R-Sq = 56.4% | | R-Sq(adj) = 54.3% | | | |

**Figure 18. Residual Plots for Regression with Alternative Price, 1.7x Cistern Assumption**

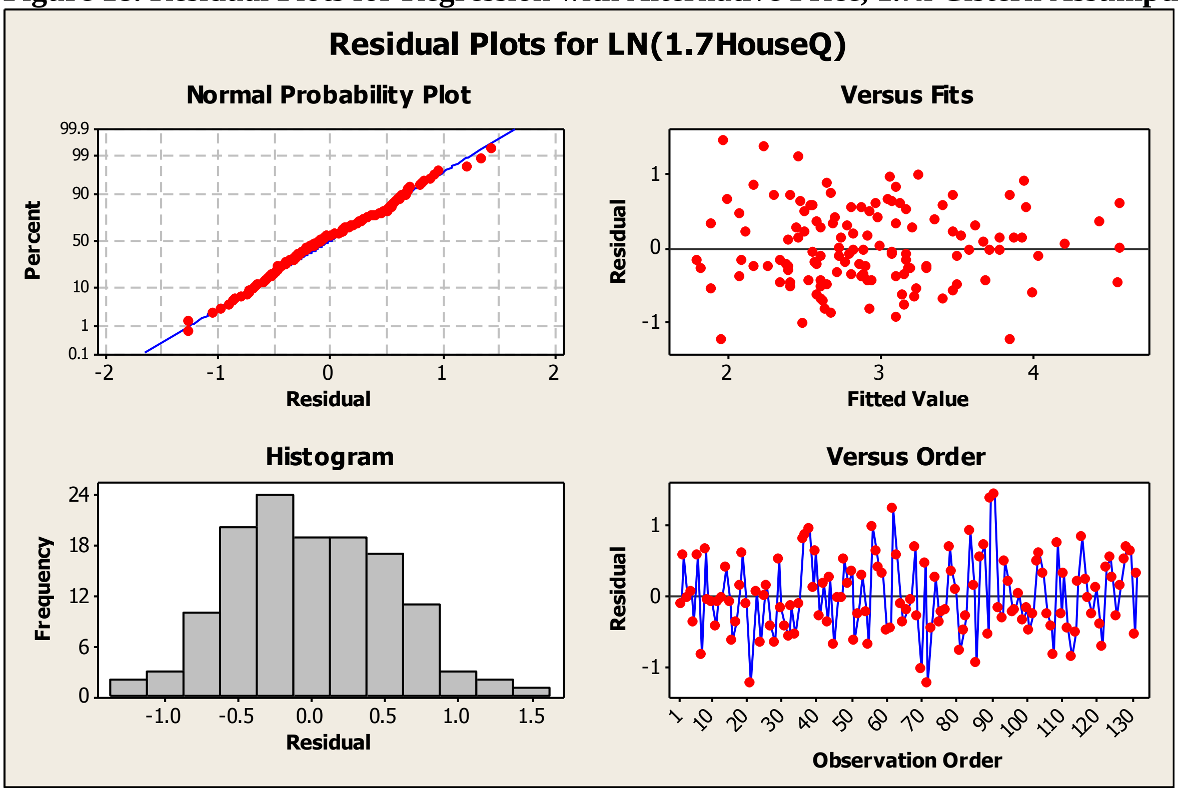
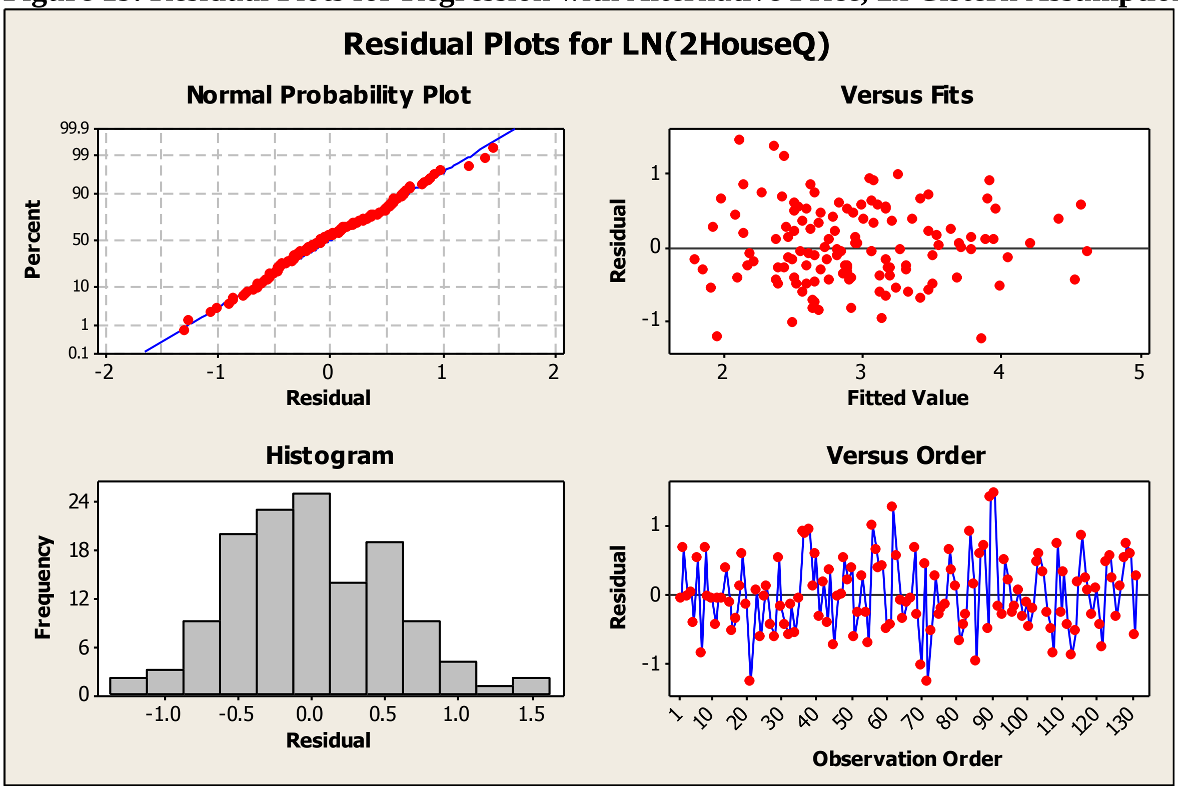


**Table 15. Assumption of Yield Equal to 2x Amount Reported Maximum Storage, using the Alternative Price**

| Predictor | Coefficient | SE Coefficient | T-Value | P-Value | P-Value (Calculated) |
|---|---|---|---|---|---|
| Constant | 3.0367 | 0.3114 | 9.75 | 0 | 0 |
| LN(2Price2) | -0.46334 | 0.09404 | -4.93 | 0 | $1.221 \times 10^{-6}$ |
| LNHouse | 0.65806 | 0.07486 | 8.79 | 0 | $3.665 \times 10^{-15}$ |
| 2D | 0.05459 | 0.01475 | 3.7 | 0 | $1.581 \times 10^{-4}$ |
| LN(NDWI2max) | 1.3918 | 0.6557 | 2.12 | 0.036 | 0.018 |
| LN(PrecipitationMedian) | -0.15489 | 0.02872 | -5.39 | 0 | $1.587 \times 10^{-7}$ |
| LN(Uncertainty) | 0.2431 | 0.1276 | 1.91 | 0.059 | 0.029 |
| R-Sq = 55.7% | | R-Sq(adj) = 53.5% | | | |

**Figure 19. Residual Plots for Regression with Alternative Price, 2x Cistern Assumption**



## *Appendix C. Survey*

| A: General Information | | |
|---|---|---|
| **Date:** | **Interviewee:** | **Organization:** |
| **Community Name:** | **District/Governorate:** | |
| **Population:** | **Area (A,B,C):** | |
| **Number of Family Members (people in the home):**<br><br>**Occupation (including family members):**<br><br>**Income (if this information can be comfortably gained):**<br>**Less than 1,500 NIS per month**<br>**1,500 – 3,000 NIS per month**<br>**3,000 – 6,000 NIS per month**<br>**More than 6,000 NIS per month**<br><br>**Estimate the percentage of the household income that pays for water?** | | |

| B. Water and Supply Information |
|---|
| 1. Where do you get your water?<br>a. Cisterns? (rainwater)<br>i. What is the storage capacity of your cistern?<br>ii. Do you share it with other family members?<br>iii. Does it fill up completely?<br>iv. How long does it take to use?<br>v. When did you install your cistern?<br>vi. How much did it cost?<br>vii. How long will you continue to use it?<br><br>b. Are you connected to a water network?<br>i. How many times do you receive water per week and for how many hours?<br>ii. Do you fill your storage until it’s full or until the water stops?<br>iii. Does it change in the summer vs. the winter?<br>iv. Storage capacity of tanks on the roof?<br>v. How much does it cost?<br><br>c. Tankers?<br>i. How often do you purchase from tankers?<br>ii. What is the cost?<br>iii. How long does it take for the tanker to come after you have called for water?<br><br>d. Bottled Water?<br>i. What do you use it for<br>ii. How much do you pay for it<br>iii. How much does it cost? |
| 2. Does your water usage change from winter to summer? |

| |
|---|
| 3. How much water do you use in a month, as indicated by your monthly bill and additionally incurred costs?<br>a. Does this total include tanker water? |
| 4. Do you have a debt from water?<br>a. How much?<br>b. How long have you had this debt?<br>c. Are you able to pay it off, or does it get bigger each year?<br>d. Are you worried that your water supplier will stop providing you due to the debt?<br>e. Why were you late on your payments? |
| 5. Do you feel your municipality bill has the correct amount of water you use? |
| 6. When accessing water, are you limited by:<br>a. The cost of the water available?<br>b. The amount of water available?<br>c. No water limitations whatsoever. |
| 7. How would your water consumption change if you had unlimited access to water?<br>a. Are there additional tasks that you would do?<br>b. Do you have an estimate of how much water each task uses (a lot, a little, the same as another task)? |
| 8. Removing constraints:<br>a. If the water were more available at the municipality level, would you buy more water?<br>b. How much more water?<br>c. Would you be willing to pay more for this additional water? (But less than the tanker costs?)<br>d. How much more per cubic meter?<br>e. IMPORTANT: Would you spend more money on water, if it were very cheap? |
| 9. Adding constraints (if the water is already cheap enough and they get enough water)<br>a. If water became more expensive, at what price would you consider changing your water consumption habits (how expensive is too expensive?)<br>b. What percentage of your income does this price represent? |

| **C: Wastewater** |
|---|
| 10. Do you ever reuse water?<br>a. For what tasks?<br>b. Grey water? Black water?<br>c. Would you use treated wastewater if it were free? |
| 11. Is your water clean?<br>a. Are there any tasks you would want cleaner water for? |

| **الجزء الأول: معلومات عامة** | | |
|---|---|---|
| التاريخ: الاسم: | المؤسسة: | اسم التجمع: |
| المحافظة/الحي: | عدد السكان : | المنطقة(أ، ب، ج) |

عدد أفراد الأسرة (المتواجدون في البيت)
المهنة /العمل (يشمل أفراد الأسرة)
الدخل( إذا أمكن الحصول على هذه المعلومة)
اقل من 1500 شيكل في الشهر
1500- 3000 شيكل في الشهر
3000 – 6000 شيكل في الشهر
أكثر من 6000 شيكل في الشهر
نسبة فاتورة المياه مقارنة بدخل الأسرة (تقدير)؟

**الجزء الثاني: معلومات التزود بالمياه**

1. من أين تحصل على المياه؟
   أ. خزان ارضي(بئر جمع)؟ (مياه أمطار)
      I. ما هي القدرة التخزينية للبئر؟
      II. هل تتشارك فيه مع أفراد آسرة آخرين؟
      III. هل يمتلئ البئر كليا؟
      IV. ما هي فترة استخدامه؟
      V. متى أنشأت البئر؟
      VI. ما هي تكلفة إنشاء البئر؟
      VII. إلى متى سوف تستمر في استخدامه؟
   ب. هل أنت مشترك (موصول) بشبكة المياه؟
      I. كم مرة تصلك المياه أسبوعيا وكم ساعة؟
      II. هل تملئ خزانك حتى يمتلئ كليا ام حتى تنقطع المياه؟
      III. هل تتغير الكمية بالصيف مقارنة بالشتاء؟
      IV. ما هي القدرة التخزينية للخزانات على سطح المنزل( الحجم)؟
      V. كم تكلفة المتر المكعب من المياه؟
   ج. الصهاريج (التنكات)؟
      I. عدد المرات التي تشتري فيها المياه بالصهاريج؟
      II. ما هي تكلفتها؟
      III. ما هي المدة التي يستغرقها حتى يصل الصهريج بعد الاتصال لطلبه؟
   د. مياه معبئة في زجاجات؟.
      I. ما هي استخداماتها؟
      II. كم تدفع ثمنها؟
      III. ما هي التكلفة الأسبوعية أو الشهرية؟
2. هل تتغير استخداماتك للمياه من الشتاء إلى الصيف؟

| |
|---|
| 3. ما هي كمية المياه التي تستخدمها في الشهر، كما يتبين من الفاتورة الشهرية والتكاليف الإضافية التي تتكبدها؟<br>أ. هل الكمية تشمل مياه الصهاريج؟ |
| 4. هل يوجد عليك ديون للمياه؟<br>أ. كم المبلغ؟<br>ب. منذ متى يوجد عليك هذا الدين؟<br>ج. هل أنت قادر على السداد، ام انه سيزداد كل سنة؟<br>د. هل أنت قلق من أن مزودك سيتوقف بتزويدك بالمياه نتيجة للدين ؟<br>ه. لماذا كنت تتأخر في الدفع؟ |
| 5. هل تشعر أن فاتورة البلدية تشير إلى أن كمية المياه التي تستخدمها صحيحة؟ |
| 6. عند وصول المياه، هل أنت مقيد ب:<br>أ. ثمن المياه المتوفرة؟<br>ب. كمية المياه المتوفرة؟<br>ج. لا يوجد هناك قيود على الإطلاق. |
| 7. كيف سيتغير استهلاكك للمياه عندما يكون وصولك للمياه غير مقيد؟<br>أ. هل هناك أعمال إضافية كنت ستفعلها؟<br>ب. هل تستطيع أن تقدر كمية المياه المستخدمة في كل عمل (كثير، قليل، نفس الأعمال الأخرى)؟ |
| 8. إزالة القيود؟<br>أ. إذا كانت المياه متوفرة بكثرة في البلدية، هل ستشتري مياه أكثر؟<br>ب. كم كمية المياه التي ستشتريها؟<br>ج. هل أنت مستعد للدفع أكثر لهذه المياه الإضافية؟(لكن اقل من تكلفة الصهريج؟)<br>د. كم ستدفع للمتر المكعب الواحد؟<br>ه. مهم: هل ستنفق أموال أكثر على المياه إذا كانت رخيصة؟ |
| 9. إضافة القيود (إذا كانت المياه أصلا رخيصة كفاية و يحصلون على مياه كافية).<br>أ. إذا أصبحت المياه باهظة الثمن، عند أي ثمن ستقرر أن تغير من استهلاكك للمياه؟(أي ثمن يعتبر باهظ)؟<br>ب. ما هي نسبة تمثيل ثمن المياه بالدخل الخاص بك؟ |

| **الجزء الثالث: مياه الصرف الصحي(المياه العادمة)** |
|---|
| 10. هل عمرك قمت بإعادة استخدام للمياه؟<br>أ. لأي الأعمال؟<br>ب. مياه رمادية؟ مياه سوداء؟<br>ج. هل ستستخدم مياه عادمة معالجة إذا كانت مجانا؟ |
| 11. هل المياه التي تستخدمها نظيفة؟<br>أ. هل هناك أي أعمال أنت بحاجة لمياه نظيفة لها؟ |

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