The economic impacts of large-scale water infrastructure improvements in urban Zarqa, Jordan

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Abstract

Jordan is a highly water scarce country facing acute sectoral tradeoffs in water use. Consumers in Zarqa, the country's second most populous urban area, typically receive piped water from the municipal network for fewer than 48 hours each week, and engage in a variety of costly coping strategies to mitigate water scarcity. Against this backdrop, the Millennium Challenge Corporation entered into a $275 million compact with the government of Jordan to improve the performance of piped water infrastructure and to increase the collection, treatment and reuse of wastewater, with the ultimate goal of increasing water efficiency and reducing poverty. This paper presents early quasi-experimental evidence on the effects of the Compact, using rich and diverse types of data collected at the end of the implementation period. We find evidence of several changes: self-reports of improved water pressure; increased sewerage and reduced sewage backups; and alterations in irrigation water sourcing in the Jordan Valley. We find tentative evidence for positive spillovers within Zarqa, compared to neighboring areas in Amman supplied by a different utility. One key category of anticipated impacts that does not materialize is in reduced spending on expensive alternatives to utility water. Though these results only indicate very short-term effects of this infrastructure improvement, they add to a scant body of rigorous evidence on the benefits of capital-intensive water infrastructure.

Keywords: Utility water supply, water efficiency, wastewater reuse, quasi-experiment

1. Introduction

As global population and consumption of water rise, concerns that humankind is entering a new age of global water scarcity are increasingly widespread (Postel 1997, Vörösmarty et al. 2000). To some, rising water scarcity is uniquely worrisome because this resource is essential for myriad purposes – for drinking and critical domestic uses, as an input to food and industrial production processes, and for general human and ecological well-being (Hanemann 2006). Some predict that this essentialness will inevitably lead to a zero sum game, widespread social destabilization, and environmental damage. Such alarmism is perhaps most commonly heard in the Middle East, due to the acute water scarcity that many of its societies already face. Yet this perspective also overlooks the fact that much of the globe already experiences acute economic water scarcity, due to a lack of high quality infrastructure and an inability for quasi-public institutions to consistently provide the resource to end users (Rijsberman 2006).

This study concerns the effects of improvements in the delivery of urban water and sewer services in Jordan, one of the most water poor countries in the world (Haddadin 2006, Schyns et al. 2015). In 2016, the country had a per capita annual water share of 121 m^3, nearly 3.5 times below the average of other arid Middle Eastern countries, and more than 50 times below the world average (FAO 2016). In recent years, population growth, urbanization, an influx of refugees from Iraq and Syria, and extremely high water losses, have all intensified this strain (Hashemite Kingdom of Jordan 2016). These growth trends and water losses have been particularly high in Zarqa and Ruseifa, the areas that were targeted by the investment. [1] For example, 57% of water produced by the Water Authority of Jordan (WAJ) in Zarqa is non-

[1] A general definition that covers both physical and administrative water losses is one pertaining to volumes that fail to produce revenues (i.e. non-revenue water, or NRW). Such water losses typically result from degraded and leaking pipes in the distribution system, broken meters, illegal water usage, poorly installed meters, and/or weak governance (Al-Ansari et al. 2014). These losses contribute to poor cost recovery, and to a lack of maintenance and further degradation of water delivery systems, both of which exacerbate water scarcity. Al-Ansari et al. (2014) estimated that water losses countrywide reached 75 million Jordanian Dinar (JD) in 1998 (equivalent to 154 million 2014 USD), and predicted that this figure would continue to grow as population increased. Consistent with this expectation, the volume of NRW country-wide has increased from 124 million m3 in 2000 to 183 million m3 in 2013 (MWI 2013).

revenue water (NRW), well above global and national averages (MWI 2013). Households and enterprises in Zarqa experience burdensome and routine water shortages; although 97% of households have access to piped water, nearly 30% of households are thought to consume less than the minimum amount of water that the World Health Organization considers necessary (60L/capita-day) for personal hygiene and food safety (MCC 2009). Households in Zarqa cope with highly irregular water supply and receive water only intermittently (Orgill-Meyer et al. 2018).

The water investments discussed in this paper were largely funded by the Millennium Challenge Corporation (MCC), which entered into a water sector compact with the Government of Jordan (GoJ) in 2009, based on identification of this sector's constraints as critical in limiting economic development, especially in Zarqa. Construction began in 2014, and the infrastructure handover was completed at the end of 2016. Data collected from locations exposed to varying types of improvements and effects over the period spanning construction thus capture preliminary effects of these investments. In attempting to evaluate this project, we confront a variety of challenges that are often encountered in assessments of large infrastructure projects. We estimate changes among households in Zarqa using a combined matching and difference-in-differences (DiD) quasi-experimental strategy; examination of downstream effects of increased wastewater reuse among irrigators then leverages a natural experiment (and DiD) occurring in the Jordanian agricultural sector.

We find evidence of several changes in areas exposed to different types of improvements, including reports of improved water pressure, increased network water use, and evidence of increased sewerage and reduced sewage backups. We also find evidence of evolving sourcing and quality of irrigation water being used by downstream farmers in the Jordan Valley, changes that are consistent with anticipated impacts on broader water system dynamics in the region. We also observe tentative support for the idea that the investment may have generated positive spillovers may within Zarqa, compared to neighboring areas in Amman that are supplied by a separate utility. These positive changes notwithstanding, a key category of anticipated impacts – reduced spending on expensive alternatives to utility water – does not appear to have materialized. Though we cannot be certain about the precise reason for this lack of cost savings to households, several potential explanation include low confidence in the quality of network water, insufficient improvements in reliability, and/or sticky or persistent behaviors regarding water sourcing.

The evidence presented in this paper adds to a surprisingly thin empirical literature on the economic benefits of large water infrastructure (Cox et al. 1971, Hanemann 2006). We also provide new evidence on the economic burden of unreliable water supplies in a particularly water-poor country in the Middle East, which is ground zero for many who make dire predictions about the potential for the negative effects of water scarcity. This evidence is timely because one of the Jordanian government's major current objectives, supported by numerous policy reforms and changes in the water sector, is to improve water security among urban residents (Royal Commission for Water 2009).[2] Various reforms are occurring in a complicated political economy context that strongly constrains opportunities for reform through more rational pricing of water, due to widespread popular opposition to higher water bills (Haddadin 2006).

In Section 2, we describe the study setting in more detail and provide a summary of related empirical literature covering the benefits of improved water and sanitation infrastructure. We describe the evaluation design, data collection activities, and sampling approach in sections 3. Section 4 provides a description of the baseline survey results, and Section 5 explains the econometric approach used to analyze midline impacts. We provide a summary evaluation results in Section 6, and conclude in Section 7.

2. Study setting and relevance of prior literature

[2] These reforms include the corporatization of municipal water utilities, reallocation of water to higher value users, and a supply-oriented strategy that is pursuing development of expensive alternative water sources, such as the Red-Dead desalination and pipeline project.

2.1. Description of the setting and intervention

Zarqa Governorate, located just to the east of the Jordanian capital of Amman, is the third most populous governorate in Jordan, with about 1.36 million people. Most of this population lives in Zarqa City (the second largest city in Jordan; population ~802,000) and Ruseifa (4th largest city; pop ~482,000), both of which lie in the Zarqa River Basin. Inhabitants of these cities have considerably lower income than those in neighboring Amman, and water is highly rationed (Jaber and Mohsen 2001). Zarqa's water availability problems are exacerbated by high water losses from the system: In 2013, it was estimated that 57% of the water produced by the Water Authority of Jordan (WAJ) utility in Zarqa was NRW, well above the national average (Haddadin 2006; MWI 2013).

Households and enterprises in Zarqa cope with highly irregular water supply and receive water only intermittently, typically between 24 and 48 hours per week.[3] In addition to water scarcity and reliability problems, households perceive the quality of utility water in Zarqa to be very low, and there is particular concern about the regular depressurization of pipes and the potential for infiltration of untreated water into the distribution network (Haddadin 2006). Meanwhile only about 70 percent of households have connections to the sewer system. The balance of households rely on septic tanks to manage wastewater, which adds to the potential for contamination of the network (through infiltration) and groundwater, an important source of water supply used by the urban utility and by water vendors. Collectively, these conditions lead to high coping costs for households, especially those related to sourcing from alternative water supplies (namely shops or tankers), investments in household storage infrastructure, and the regular emptying of septic tanks (Orgill-Meyer et al. 2018). The lack of reliable supply and a negative perception of network water quality help to explain why there is significant resistance to raising utility water bills (Pitman 2004, Sommaripa 2011), which could theoretically improve the utility's ability to provide timely and effective maintenance services, and thereby reduce NRW.

[3] Nearly all (>99%) households are connected to the utility network. Enterprises on the other hand have much lower connection rates (<50%), reportedly because of high connection fees and tariffs that serve to cross-subsidize household water consumption.

Following a detailed project identification and preparation period, the MCC entered into the multi-year, $275 million Jordan Compact (JC) with the GoJ in December 2011.[4] The implementation period spanned five years and ended in December 2016, with all infrastructure works completed on time and within budget. The final JC included three inter-linked projects:

(i) The **Water Network Project** (WNP) comprised two activities. The first of these was the rehabilitation and restructuring of water supply transmission and distribution infrastructure plus replacement of domestic water meters, in both Zarqa and Ruseifa. The aim was to improve overall water system efficiency; this objective would be achieved through reduction of physical water losses and a transition from periodic distribution under high pressure to more consistent, gravity-fed distribution. The second activity, Water Smart Homes (WSH), aimed to improve household water storage and sanitation through a general outreach campaign, as well as delivery of infrastructure and technical assistance targeted to the poor.

(ii) The **Wastewater Network Project** (WWNP) encompassed the expansion, rehabilitation and reinforcement of the wastewater network in Zarqa Governorate, and aimed to improve wastewater system efficiency and increase the capture of municipal wastewater.

(iii) The **As-Samra Expansion Project** (AEP) was designed to raise the capacity of the existing wastewater treatment plant serving this region, to allow treatment of additional wastewater volumes resulting from population growth in both Amman and Zarqa, and from the aforementioned WNP and WWNP investments.

The stated goals of the projects comprising the JC – to reduce poverty and stimulate economic growth in Zarqa Governorate – were ambitious. These goals were to be achieved by increasing the supply of water available to households through improvements in the efficiency of water delivery, the extension of wastewater collection and the expansion of wastewater treatment.

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[4] This preparation phase involved an analysis that was aimed at identifying key challenges to economic development in Jordan (a constraints analysis), identifying a technical solution to some of those challenges, and conducting feasibility and economic analyses of its anticipated impacts. More information on how MCC works can be found at https://www.mcc.gov/.

Ex ante, planners believed that the economic rationale of the investment would be manifest through three main mechanisms: two primary water substitution mechanisms, plus the household cost savings on costly evacuation of septic tanks stemming from new connections to the sewer system. The first (primary) water substitution effect would allow greater reuse of treated wastewater by downstream irrigators in the Jordan Valley (JV). This would in turn free up freshwater resources coming from the north of the country, via the Yarmouk River and Lake Tiberius, for higher value urban uses. Alternatively, it would allow preservation of high value agriculture under conditions of increasing water scarcity, if such diversion of freshwater occurred anyway, which would be consistent with official policy (Royal Commission for Water 2009).[5] Figure 1 provides a visual and qualitative representation for this primary substitution mechanism. The logic behind the second (secondary) substitution effect is more intuitive: This would occur through households' switching away from high-cost non-network water vendors (i.e., distribution shops and tankers) to greater use of cheaper network water.

Many potential sub-mechanisms and assumptions underpin these three main channels for generation of economic benefits, as depicted in a more complete project logic diagram (see Figure A1 in the appendix). Here it is worth highlighting several of the additional channels that might prove particularly consequential. First, households might experience changes in health and general well-being arising from shifts in sourcing and in consumption levels, or other behaviors targeted in the outreach campaign. Second, it is possible that the water utility would capture most of the benefits of the investment, with direct implications for cost recovery and utility performance, and indirect implications for public debt and long-term quality of service

[5] We note here that there is some dispute over the specific *ex ante* accounting of economic benefits from the JC, which is discussed in additional detail in the Evaluation Design Report. The main point of contention relates to whether the expansion of wastewater treatment in the AEP would materially change outcomes for downstream irrigators. On the one hand, it is unlikely that treatment of the additional flows of wastewater to standards would have a meaningful effect on water quality parameters relevant for agricultural production in the JV, because the practical concern with reuse in the JV is primarily about salinity and not microbial contamination, and the former is unchanged by the AEP. Concerning the latter, there is dilution with Zarqa River freshwater plus a long residence time in the environment prior to reuse. On the other hand, there is a perception that reuse of only partially treated wastewater in the JV could harm marketing of crops grown in the region, even if the risk of contamination is negligible. To be sure, Jordan's farmers have suffered the consequences of such negative perceptions of quality before, as discussed in Jeuland (2015).

delivered to households. Third, there could be changes through firm-level water decisions, and perhaps especially those of water shops and tankers, which could themselves affect economic outcomes. Finally, the switch in irrigation water sourcing has major implications for farmers growing crops that are sensitive to salinity, for example citrus farmers in the north JV.

2.2. Relevant literature

The limited availability of studies pertaining directly to the hypothesized linkages between water and development, and more specifically focusing on urban populations similar to the JC's target population, makes it difficult to rely on past evidence and experiences to make predictions that are directly relevant to this intervention. Likewise, there is scant literature on the impacts of large-scale water interventions in middle-income settings. Indeed, most of this literature – reviewed below – focuses on impacts on populations lacking any access to improved water, sanitation and hygiene (WASH) services.

At the network level, the literature holds that investments in urban water supply lead to lower input costs; firms using improved services thus respond with expanded production and employment, reduced prices, and increased investment (Schwartz and Johnson 1992). Gains at the enterprise and industry level then translate into increased production and income. Furthermore, water supply investment is likely to reap the greatest benefits where small distribution systems can be expanded at relatively low cost, where water is a major input to production, and where the current price and quality of alternative supplies is inadequate (Schwartz and Johnson 1992). At the household level, most studies that point to significant coping cost savings – in health and time – pertain to rural areas in low-income countries (Whittington et al. 1990). In a multi-country study, a 15 minute decrease in one-way walking time to water source was associated with a 40% average relative reduction in diarrhea prevalence, improved anthropometric indicators of child nutritional status, and a 10% relative reduction in under-five child mortality (Pickering and Davis 2012). Increased water access can increase household savings and free up funds and time for other pursuits (Galiani et al. 2009). The benefits of improved water supplies further depend on the characteristics of existing and improved sources, such as price, reliability, convenience, and quality (Cairncross and Kolsky 1997). Also important is whether the improvements can be sustained over time while keeping costs low. Suppressed water rates commonly levied in the Middle East, for example, are closely tied to water shortages and reduced performance of utilities over time (Bucknall et al. 2007, Jeuland 2012).

Women in particular are often the primary beneficiaries of water supply interventions, as they gain from the take-up of income-generating opportunities and education enabled from time savings due to increased access to water (Cairncross and Kolsky 1997). Such productivity benefits are likely to be lower in urban areas relative to rural settings. Nonetheless, supply disruptions that require staying at home (to monitor taps), or that require travel to obtain water from shops or other out-of-home locations, may fall disproportionately on women, even in urban or peri-urban contexts. Devoto et al. (2011) found that while greater access to clean water saved households a significant amount of time in urban Morocco, this time was spent primarily on leisure and social activities.

Overall, there are mixed findings on whether increased water availability improves health at the household level. One of the major challenges plaguing observational studies of the impacts of improved water and sanitation services on outcomes is that households with improved services tend to be systematically different from those without them (in terms of socio-economic status (SES), risk-altering behaviors, and unobserved preferences for health), rendering comparisons of those with and without access suspect. Multiple channels influence the incidence of diarrhea, and many of these are unrelated to water access, such as hygiene practices, contamination problems related to in-house water storage, sanitation, and exposure to food-borne pathogens (Zwane and Kremer 2007, Waddington et al. 2009). Early systematic reviews of water supply interventions suggested a weak link between improved household water quality and diarrheal disease control (Esrey et al. 1991, Lewin et al. 1997). Recent randomized trials and systematic reviews of evaluations of water supply improvements in less-developed countries do not generally support that result, however (Fewtrell et al. 2005, Waddington et al. 2009, Devoto et al. 2011). More positive evidence exists linking expanded piped water access and quality to health, especially among higher mortality populations (Jalan and Ravallion 2003, Galiani et al. 2005, Gamper-Rabindran et al. 2008, Alsan and Goldin 2015).

Water quality improvements, on the other hand, have been more conclusively linked to health benefits (Fewtrell et al. 2005, Clasen et al. 2006, Waddington et al. 2009). Cutler and Miller (2004) use the natural experiment arising from differential timing of the introduction of chlorination in large cities in the US to link water treatment to reduced rates of typhoid and cholera. A study in rural Jordan highlights the difficulty in pinpointing the origin of diarrheal disease; in 35% of study cases, the etiologic agent could not be determined despite the wide prevalence of diarrheal disease, suggesting that diarrhea-causing pathogens circulate easily through the population, and not necessarily through water (Nimri et al. 2004). Meanwhile, low maternal education has been found to be a significant risk factor for childhood diarrheal incidence in northern Jordan (Nimri et al. 2004). In general, the effectiveness of water quality interventions for preventing diarrhea may be more closely related to compliance with the intervention (behavior change) than the specific intervention type (Newman et al. 2002, Clasen et al. 2007). Achieving compliance meanwhile remains a persistent environmental health challenge. Even salient behavior change education has been shown to have modest, heterogeneous, and short-lived effects (Jalan and Somanathan 2008, Luoto et al. 2011, Hamoudi et al. 2012, Brown et al. 2016).

With regards to improvements in sanitation, large-scale systematic reviews again suggest a potentially larger impact on health than for increased water availability (Fewtrell, Kaufmann et al. 2005; Waddington, Snilstveit et al. 2009). Unfortunately, most of the evidence from rigorous impact evaluations comes from rural studies that focus on the transition from open defecation to latrine use (as opposed to the shift from on-site sanitation to sewerage) (Pattanayak et al. 2009, Pattanayak et al. 2010, Duflo et al. 2015, Hammer and Spears 2016). Whether moving to sewered sanitation and treatment systems from on-site excreta disposal in densely populated urban areas would affect health and other aspects of well-being is unknown. The question is of great importance, however; throughout Jordan for example, recent data suggests that only 88% of domestic wastewater is estimated to be collected in sewers, and only about half of this amount (47%) is treated in wastewater treatment plants (Jeuland 2012). Another relevant finding in the literature on water and sanitation interventions is that individual interventions seem to deliver diarrheal disease reductions of 30-40%, but combined interventions offer little additional benefits (Fewtrell, Kaufmann et al. 2005; Waddington, Snilstveit et al. 2009). This is puzzling because such interventions often target different channels of contamination. It may result from problems with study quality, coordination challenges during implementation, compensating behaviors, or misattribution of benefits to individual interventions (Eisenberg et al. 2007, Whittington et al. 2012, Jeuland et al. 2015).

A key anticipated outcome of the JC is reduced demand for and usage of expensive water sold through the private sector. Literature and observational evidence supports the general assumption that improved water availability leads to greater water consumption, but the extent to which households are willing to substitute vended water for network water may be determined by a number of factors unrelated to structural interventions. A study of water vending and willingness to pay in urban Nigeria emphasizes the significance of perceptions of water quality: people were willing to pay water vendors over twice the operation and maintenance costs of piped water for what they perceived to be higher quality water, despite vast structural improvements made to the piped water system (Whittington et al. 1991). Demand for water supply improvements among small enterprises in two Ugandan towns has similarly been found to be limited due to quality concerns (Davis et al. 2001). In Jordan, Orgill-Meyer et al. (2018) show that urban consumers are willing to pay very little for improvements in water reliability, which they partly attribute to imperfect substitutability with shop water.

Examined through the lens of the economic analysis justifying the JC, success of the intervention largely hinges on the effective substitution for irrigation of recycled wastewater for currently-used freshwater supplies. The conditions leading to this type of substitution are not well understood, however. In Jordan, reuse of mixed water is already well-developed and enabled by a combination of heavy water subsidies and a lack of choice over irrigation water source (Jeuland 2012). Studies in the Middle East and globally additionally indicate that acceptance of new irrigation methods largely depend on farmers' attitudes toward production risk, perceptions of the risk, and potential profitability (Foltz 2003, Koundouri et al. 2006). In effect, a number of water-scarce countries, including Jordan, have made significant efforts at promoting wastewater reuse in agriculture, often with relatively limited success due to lower demand for recycled water that is high in salinity or of unknown microbiological quality (Carr et al. 2011, Jeuland 2015). To the best of our knowledge, there have been no IEs of wastewater reuse examining areas where such water has replaced freshwater supply.

One of the primary reasons why the IE literature on the effects of regional or urban water and sanitation infrastructures is so thin is that such studies are difficult to conduct in an experimental or quasi-experimental framework. Additionally, the literature cited in this review has noted important limitations that make it difficult to estimate the true causal impact of large-scale water interventions. First, due to the nature of the scale of intervention, specific impacts at the household level are difficult to attribute to large, multi-pronged activities that in fact include a package of interventions. Specifically, observed differences in outcomes for beneficiaries of large-scale interventions may arise from a combination of factors, some of which are unrelated to the intervention itself, making the true impact more difficult to tease out. Moreover, a distinct feature of urban water interventions is the partial coverage of populations that may differ in other important ways; in many cities, geographic clusters of households are connected to pipes, while other clusters receive water from a variety of sources, such as tanker and shop water (Lokshin and Yemtsov 2003). In addition, access to services may not always coincide with high quality and reliability, particularly in the long term (Zérah 1998). Finally, infrastructure interventions is a blunt instrument, so a traditional IE may have limited ability to capture the various important phenomena surrounding water use.

3. Study design, sampling, and data

Evaluation design

Developing a rigorous impact evaluation design for a large infrastructure intervention like the JC is a considerable challenge. Foremost among the difficulties of this task is the question of how to obtain a sample that approximates the non-intervention counterfactual. Given the integrated nature of the program's economic logic and its effects on multiple sectors as discussed above, a sound evaluation must endeavor to approximate this counterfactual across a diverse set of actors and geographies. Other challenges pertain to the generalizability of measured results from samples that have better internal validity, statistical power, accounting for spillovers, and adequately contextualizing and controlling for non-intervention confounders.

Careful consideration of these various challenges ultimately led to the design of a three-component impact evaluation (summarized in Table 1). Component 1 aims to measure impacts in Zarqa Governorate. It will ultimately comprise 1) longitudinal household and enterprise surveys carried out in intervention and control areas of the Zarqa/Ruseifa conurbation, as well as control areas selected from neighboring areas in East Amman; 2) endline cross sectional surveys of water vendors and refugees arriving during JC implementation; and 3) qualitative work to understand the infrastructure component of the WSH program supporting poor households in Zarqa. Component 2 aims to estimate the impacts of the primary water substitution effect. It consists of longitudinal farm surveys in locations downstream of the As Samra WWTP, coupled with a systems-based water balance analysis developed to identify changes in the availability and utilization of alternative water sources for irrigation and urban uses. Component 3 includes monitoring of utility-level data on water delivery, wastewater collection, and financial and technical performance of the utility in Zarqa, and comparison with changes in these variables among the other utilities operating in Jordan.

As noted in Table 1, this paper focuses on the methods and results pertaining to a limited subset of the elements in Components 1 and 2. Regarding the first of these, the evaluation design had to consider that intervention (hereafter "treatment") areas within Zarqa were not randomly selected for infrastructure improvements, and that these likely differed from potential comparison non-intervention ("control") areas. To deal with this issue, we implement a strategy of matching on pre-intervention characteristics plus difference-in-differences (DiD) analysis (Jeuland et al. 2015). The *ex ante* matching allowed us to select Census block-level geographic zones that were to be differentially treated by the JC but that appeared observationally similar prior to this intervention. DiD meanwhile gives us additional confidence in measures of its impacts by netting out remaining unobserved and time-invariant pre-existing differences across the units in the matched areas. The key identifying assumption remains that key time-varying differences are also balanced across these zones. We are able to validate this parallel trends assumption by comparing pre-intervention trends in at least one key variable that pertains to water sourcing, that is water consumption from the utility network.[6]

Specifically, we created three different sets of matched units using data from the most recent prior Census conducted in 2004. The first set matches areas "treated" with the WNP alone with unaffected "control" units; the second matches WWNP-only areas with controls; and the third matches areas treated with both the WNP and WWNP improvements to controls.[7] In addition, because we were concerned about the potential for utility-wide spillovers within Zarqa, control samples were created in both Zarqa Governorate and in East Amman, the urban zone nearest to Zarqa that was served by a different utility. A map of the final sample zones selected for surveying in Zarqa is shown in Figure 2. Pre- and post-matching sample zone characteristics are summarized in Tables 2 and 3, and parallel trends in pre-intervention water consumption in

[6] We are also attempting to obtain information on pre-intervention trends in connections to the sewer network, to validate pre-intervention parallel trends in the other key hypothesized impact channel, i.e., savings related to reduced wastewater pumping from septic tanks.

[7] We used a 1-1 nearest neighbor propensity score matching (PSM) procedure in which the first stage was specified as a logistic regression model that estimated the probability of treatment as a function of 11 variables measured or calculated from the Census data, namely: Wealth index (created from a range of asset and housing variables); marital status, gender education level, and employment of the household head; residency in years, % handicap, % non-Jordanian, population density, # of buildings, and # of households. More detailed description of the approach and results of the first stage are provided in Appendix B. In the second stage, untreated units with the closest predicted probabilities of treatment were matched to treated areas of each of the three types.

Table 4; these show that the matching approach was successful in removing differences in Census characteristics across zones.[8]

Evaluation Component 2 is focused on the primary water substitution (additional reuse of wastewater in agriculture and substitution of scarce freshwater to urban areas) and its impacts on irrigators. In this component, we exploit the natural experiment of temporal and spatial variation in the source and timing of water supply to farmers. This variation arises as a dual consequence of natural hydrological variability and a gradual tightening of water supplies in Jordan due to urban population growth. The natural experiment is supposed to accelerate following the JC investments, which facilitate a transition into greater reuse of treated wastewater and away from freshwater in the JV. It is important however to emphasize that the changes observed in the JV are not wholly due to the JC, however. Other investments – in expanded wastewater management capacity and treatment, and in conveyance infrastructure – also play a role in this transition.

To observe these changes, we apply DiD analysis to longitudinal farm-level data collected from 4 different areas located in the JV. These areas are characterized along a continuum that ranges from primary use of freshwater from the Yarmouk River and Lake Tiberius, in the Northern zones, to primary use of blended water (treated wastewater mixed into the Zarqa River), in the Middle to Southern areas. A fifth area along the Zarqa River in the highlands is also included since agricultural expansion may occur there as a consequence of augmented upstream production of treated wastewater. We contextualize these farm-level changes using systems-based water balance modeling that helps isolate the relative contribution of the Compact investments to the changing water supply. A systems model is needed to account for other dynamics such as hydrological variability, expansion of alternative water supplies, and other changes that lead to increased reuse of treated wastewater, for example, from other

[8] Unfortunately for the evaluation design, during Compact implementation, the areas served by the WWNP were expanded due to cost savings in some of the planned project areas, such that the sewer expansion was extended into some control neighborhoods (this expansion affected roughly 100 sample households). Our main analyses maintain the classification of these contaminated areas as controls; we also test robustness when the affected areas are omitted from the analysis.

cities supplying treated wastewater to the JV. An illustrative schematic depicting the sample areas and how they relate to the water balance is shown in Figure 3.

Sampling and data collection

All survey results discussed in this paper are longitudinal and based on comparison of baseline and mid-line (near the end of JC implementation) surveys. That is, we only discuss data collected through late 2016 from study households and farmers (since we only have baseline data for enterprises). The specific timing of the surveys, relative to the implementation of the JC improvements, is illustrated in Figure 3.

On the basis of the results of the matching procedure for Component 1 and pre-intervention power calculations that are detailed elsewhere (Albert et al. 2014), 325 Census clusters in Amman and Zarqa were retained for the household surveys, with a target of 3575 households (or 11 per cluster) overall.[9] Households were then randomly selected from a sampling frame that had been updated by Jordan's Department of Statistics shortly before the baseline survey. For the agricultural surveys in Component 2, 110 farms were randomly selected from lists of farms operating in each of the five sample areas (550 in all). Accordingly, the samples may not be representative, of households and enterprises in Zarqa and Amman, on the one hand, and of farmers in the Jordan Valley and highlands, on the other.[10] Due to challenges in locating households and refusals, the final sample size for the baseline survey fell somewhat short of the initial target, an issue that was addressed by adding households in subsequent surveys (see appendix Table C1).

[9] Additional details and discussion can be found in the Evaluation Design Report, which is available at: https://data.mcc.gov/evaluations/index.php/catalog/103.

[10] Nonetheless, we did compare sample characteristics with those from representative surveys conducted by the Department of Statistics (for agriculture and households), the Land Registry of the Jordan Valley (for farms) and the World Bank Enterprise surveys (for enterprises). For the farm survey, this comparison indicates that our sample mostly cultivates land in accordance with the distribution of lands recorded in the land registry, with some differences, most notably greater cultivation of tree and vegetable crops overall. Differences in asset wealth may also reflect capital accumulation since that piror Census in 2006. For households, our sample has higher income, smaller household size, and lower use of tanker water, relative statistics reported in a 2009 DoS Water Survey, but the differences are modest. More detailed comparisons are available from the authors upon request.

For each of the surveys, enumerators from Jordan's Department of Statistics were trained to collect data using electronic survey instruments that were thoroughly pre-tested prior to deployment. The household survey included 13 modules and took approximately 40 minutes to complete. It was developed to collect information on household demographics; water sourcing (including network, tanker and shop water), storage, and use behaviors; preferences and satisfaction with water and sewer service; water quality measured at the tap and in in-house storage containers for a sub-sample (E. coli and thermo-tolerant coliform counts); coping and health costs related to intermittent water supply and poor water quality; and expenditures, income, and other socio-economic characteristics. The agriculture surveys, which took roughly 1 hour to complete, recorded information on basic farm characteristics (soils, canal location, etc.); inputs and costs; outputs and revenues; advantages and constraints; assets and equipment; animal husbandry; irrigation water situation and management; willingness to pay (WTP) for more dependable irrigation water supply (of blended, not freshwater); and socio-economic status and characteristics of the farmer. Instruments used in the follow-on surveys with households and farmers were slightly shorter than those deployed at baseline.

4. Description of the household and agricultural samples at baseline

Household sample

The average household size in the sample was 4.9 people at baseline in 2014, with 0.4 children per household under the age of 5, and 3.0 adults over the age of 18 years (Table 5). Most households are Jordanian (93%); 85% have a male head of household. Education levels in the sample are generally high: 91% of respondent had no trouble reading a written newspaper article, and enumerators judged that 87% had no trouble understanding the survey. The average years of education among all household adults was reported to be 10.6. Seventy-three percent of respondents own their residences, 55% of which are apartments or flats. On average, households report spending slightly more (450 JD/month) than they earn (426 JD/month).[11] Finally, ownership of household durable goods and vehicles varies: nearly all

[11] 1 JD = US$1.41.

(98%) own a washing machine, but slightly fewer than half of households own a computer (45%) and at least one vehicle (45%), respectively. Twenty percent own at least one air conditioner. The Zarqa sample has slightly lower income and expenditures (409 JD/month and 429 JD/month, respectively), but most variables are balanced across the Zarqa and Amman sub-samples.

Turning to water and sanitation-related variables, household connection rates to utility water and sewer in our sample were 97% and 79% respectively in 2014. A large percentage (39%) of households share water meters with others. For the 75.9% of households who produced a bill or otherwise provided self-reported estimates of network water consumption, the average monthly amount used was 7.7 m^3 (see Figure 5 left panel for the distribution of these monthly amounts in the sample). Meanwhile, households expressed relatively low confidence in the quality of water obtained from the utility network, rating the safety of that water to be 5.1 on a 10 point scale ranging from not safe at all to completely safe. Households however considered their own drinking water (which may be treated or obtained from other sources) to be 8.2. An average of 0.15 members per household reported having a case of diarrhea in the prior 2 weeks (representing an incidence of about 2.9%), and 0.048 reported suffering from some other water-related illness (1.0% incidence). On a 5-point scale, households rated their sanitation situation to be 2.83 (closer to acceptable (3) than good (2)).

Households used a variety of non-network water sources at baseline (44% use at least one other source), and shop water was by far the most frequent alternative, with 38% of households purchasing it. The quantity of water taken from non-network sources (0.38 m^3/month) was far lower than the average network consumption (see Figure 5 right panel). While 34% of households change their water consumption patterns in the alternative (winter) season, very few households (<1%) change sources. Twenty-three percent of households reported experiencing water shortages; a somewhat higher proportion (29%) experienced shortages in Zarqa. Households reported receiving water 9.2 days per month on average (and 8.3 days per month in Zarqa). Water and hygiene behaviors were also variable in the sample.

Thirty-five percent of households reported treating water in house at the time of the survey, and most of these (34%) were able to show enumerators a sample of treated water during the visit. Most of these households (90%) consumed treated water less than one day after treatment. A large majority of households (88%) also had soap at the time of the visits.

There was some variation in the quality of the household samples that were tested. These samples were collected from storage containers; their quality is thus likely affected by storage and handling within the home. We found little evidence of *E. coli* contamination problems: It was below detection (1 colony-forming unit per 100 mL sample) for *all* tap water samples collected from household storage tanks. Three of 91 samples that had been sourced from water shops and subsequently stored at home showed modest E. coli contamination (7, 28, and 54 CFU/100mL, respectively). Unsurprisingly, there was somewhat higher prevalence of total coliforms in stored water: these were detected in ~10% of the tap water samples, though counts were generally low: All samples except one had less than 100 CFU/100mL. Finally, likely due to the fact that such water is stored for longer periods of time, we detected total coliforms in over 70% of shop water samples, with 29% of samples having more than 100 CFU/100mL and 11% more than 1000 CFU/100mL. Collectively, these results suggest that dangerous levels of microbial (*E.coli*) contamination are not widespread in this sample, but that storing water for long periods may elevate risks.

Using the extensive data collected in the baseline survey, we were able to estimate water- and wastewater-related expenditures, and compute coping costs in different categories (e.g., time spent collecting water from alternative sources, or in-house water treatment costs). The calculation of various components of these coping costs are described in more detail in Appendix D, and baseline data is summarized in Table 6 and Figure 6 (see also Orgill-Meyer et al. (2018) for additional analysis and discussion of these results). As shown, households spend about 6.2 JD/month on network water and sewer; the amount is only slightly lower (5.8) in Zarqa. The largest category of water-related coping costs is for purchase of non-network water (roughly 6.5 JD/month), which is striking given the much lower amounts of non-network water that are consumed; the possibility of reducing this significant expenditure is one of the key motivators for the Compact. Households spend another 5 JD/month on water collection, treatment, storage, and on repairs to household infrastructure, such that overall water-related coping costs are 11.5 JD/month (and 11.8 JD/month in Zarqa). Wastewater-related coping costs are primarily in pit emptying (3.2 JD/month) and toilet infrastructure (6.5 JD/month). The wastewater-related coping costs in the full sample and in Zarqa are similar (9.9 JD/month vs. 9.6 JD/month).

Agriculture sample

The average age of sample farmers is 52.1 (Table 7). Most (95%) are Jordanian (94%), married, and average household size is about 5. Half of these farmers own their farm; the average farm size is 38 dunums, 32 of which are cultivated. The average farm value was reported to be worth 166,700 JD. Most farms did not have buildings (residence, storage facilities, or livestock buildings) on their land. Eighty percent of farmers reported growing crops in the winter in the prior year, and 40% grew crops in the summer. Reported average monthly incomes and consumption were 1297 JD and 892 JD, respectively. The average farm had about 22,400 JD in assets, with 7,190 JD of this asset wealth being in water-related assets.

On average, farmers cultivating during the winter season (n=441) spent about 13,400 JD in agricultural inputs in 2015, with most of those costs being spent on vegetables (9,630 JD) and trees (3,250 JD). Field crops and flowers had considerably lower input costs, partly because of the smaller area and lower number of farmers growing such crops. In the summer, input costs among farmers growing crops (n=220) were slightly higher for trees (3,230 JD) than for vegetables (2,840 JD). The majority of farms (0.64) had at least one permanent worker, and the average number of permanent workers per farm was 1.55. Farms, on average, also have roughly 4 unpaid employees.

Consistent with the lower costs observed in summer, the average area of land used for farming was larger in winter than summer, though in both seasons, trees took the largest area (13.8 and

14.5 dunum, in winter and summer, respectively), followed by vegetables (12.2, and 6.97), field crops (4.56 and 3.06), and lastly, flowers (0.18 and 0.09). In winter, vegetables produced the highest output of 76 tons, followed by, trees (28.5 tons), and field crops (26.5 tons). In summer, the order was different with trees producing the greatest output (34.0 tons, followed by vegetables (16.1 tons), and then field crops (7.85 tons). On average, farms generated revenues of 23600 JD in the winter and 8860 JD in the summer.

Farmers did not report feeling very constrained by water-related issues on their farm. Their biggest reported constraint was with the irrigation water amount (ranked on average of 3.05 on a scale of 1 being excellent and 5 being very poor). Farmers ranked canal position, irrigation water quality, drainage and soil fertility as 2.87, 2.81, 2.69, and 2.29, respectively. For both the prior winter and last summer, farmers reported receiving more water (17,600 m^3 and 6,850 m^3, respectively) than they had planned on (13,900 m^3 and 5,050 m^3), on average. On average, water quality was viewed as a modest constraint (ranked 2.89 in winter and 2.78 in summer on a scale of 1 being excellent and 5 being very poor), and about half of the farmers reported having water quality problems. Few farmers found the level of water they received to be sufficient (0.36), but very few (0.07) adjusted their crop mix because of water shortages. A quarter of farms use water pumps, and on average, a farm spends 318 JD/year on these pumps and 450 JD/year on network water repairs. Only 3% of farmers used groundwater. The total payment for water is 479 JD/year.

As expected, farm characteristics and activities varied significantly across sample zones (See Appendix Table C2). Some of the most important differences are discussed here. While the total average farm area was smallest in the North Jordan Valley, more of the land in that zone was used, and there was a gradient in intensity of farming from North to South. Reported land values, meanwhile, were highest in the middle Jordan Valley and in the highlands. Farming is much more labor intensive in the South and Middle Jordan Valley; this reflects the greater production of vegetables and flowers in those regions. Trees, meanwhile, are hardly grown in the southern zones, probably due to salinity problems with reused water. Total revenues are highest in the South and Central Jordan Valley, where agriculture is more focused on vegetables and field crops. Meanwhile, water quantity and canal position are most severe constraints among farmers in the North Valley (compared to water quality and soil fertility), while, water quality and quantity are most severe in the Middle and South. Pumps and spending on water and water-related assets are highest in the South, and only farmers in the South and South Central report changing their crop mix due to water quantity problems.

Finally, we note that willingness-to-pay for a more regular supply of blended water, which was the subject of a contingent valuation exercise conducted in the baseline survey, was uniformly low in the North Jordan Valley, and relatively higher in the South Jordan Valley. This evidence is consistent with the fact that the latter zone has had experience using such water for irrigation purposes, contrary to the former.

5. Econometric strategy for analysis of mid-line results

Our analysis of the changes among households and farmers between baseline and mid-line data collection employs a difference-in-differences (DiD) strategy that nets out time-invariant unobserved differences across groups that may affect or confound interpretation of the impacts of the Compact investments. More specifically, we estimate changes in outcomes using linear regression models that take the form of equation 1:

$$Y_{ijt} = \alpha + \gamma T_t + \delta d_j + \kappa T_t \cdot d_j + \beta X_{ijt} + \delta_{ijt}, \qquad (1)$$

where Y_{ijt} is the outcome of interest for household/farm or other unit *i* in zone *j* at time *t*, *d* is equal to 1 if household *i* is in area *j*, and 0 otherwise, T_t is a dummy variable that is equal to 0 for the baseline ($t = 0$) and 1 for the mid-line ($t = 1$) period, X_{ijt} is a vector of time-varying control variables that may affect the outcome for unit *i* in zone *j* at time *t* , and δ_{ijt} is a time-varying error term. The coefficient κ measures the "treatment effect," or the change in outcome *Y* for treatment households or farms in group *j* relative to that in the other groups. This estimate is unbiased so long as the error term δ_{ijt} is uncorrelated with treatment status. Here we emphasize again that the "treatment effect" measured among farmers is not limited to the impact of the JC, but rather represents the collective effect of several contemporaneous changes (including the JC) that are differentially changing irrigation water sourcing in the JV. To test robustness, we estimate this model with and without unit-specific (household or farm) fixed effects.[12] We also estimate these models with and without including time-varying controls X_{ijt}. Standard errors are clustered at the level of the sampling cluster.

At midline, the outcomes Y_{ijt} that we consider are primarily factors that we expect to change in the very short term, since the majority of the infrastructure works had only recently been completed. For households, we thus focus on measures of the reliability of water supply, billed water consumption, perceptions of pressure and safety of network water, service disruptions and sewer backups, expenses on non-network water, sewer connections, and pit-emptying costs. Among farmers, we study water sourcing, perceptions of water quality, decisions about cropping across seasons, and total annual profits, but we emphasize again that the changes we observe cannot be solely attributed to the JC, because other complementary investments and changes – conveyance projects, population growth and related increases in wastewater flows – have already been underway for some time.

We note that κ represents an intention-to-treat (ITT) estimate; that is, it measures impacts on households and farmers whether they choose to comply with the intervention or not (Galasso et al. 2004). This is relevant especially with regards to the wastewater network expansion, because households still need to connect to the new sewer pipes, and because the sewer expansion also affected some control areas as previously noted in footnote 8. Households treated by the water network improvements, and farmers affected by changes in water supply have less ability to choose to not comply. Finally, in the case of the household analysis, the sample comparison that we make using equation 1 is between treatment households in a treatment area of a specific type (WNP-only, WWNP-only, or both) and the respective set of matched controls, and not the complete sample. For the agricultural survey, we identify

[12] This is primarily relevant for the household survey analysis, in which attrition was most significant (15%), and because we enrolled replacement households. Thus, in the model with household fixed effects, we lose sample size.

differences in changes in each zone relative to those in all other areas, since the natural experiment does not provide us with any sample that can be considered a pure control.

A key threat to clean identification of impacts using the DiD approach is that time-varying unobserved differences across groups may be responsible for differential changes that are observed, rather than the intervention (in this case, the JC). In the household survey, this threat is mitigated by the matching procedure that reduced differences within the sample, and by the parallel pre-intervention trends that we found in network water consumption. At this time, given the data we have available, we are unable to test parallel trends among farms in the Jordan Valley, and we also emphasize that the natural experiment we exploit there has already been underway for some time as per the GoJ policy. Thus, we should not expect parallel trends over the recent period, and disentangling the JC impacts from other changes is also infeasible. This is important for interpreting the trends we observe in the farm sample.

6. Results

With these points in mind, we turn to the mid-term results obtained from the analyses of outcomes using the DiD specification shown in equation 1. We first present effects of the Compact on households, and then consider the changes among farmers. To maintain statistical power (due to high attrition in the household sample) and for simplicity, we mainly focus on the specification of equation 1 that does not include household fixed effects or controls, but discuss if and how results change with inclusion of these factors.

6.1. Impacts on households

The results of our analysis of impacts on households are summarized in Table 8. Four main messages emerge from these analyses. First, there is some evidence of short-term improvements in water supply and pressure in the areas served by the Compact, and especially in the Water Network Project (WNP) areas. We expected to see only modest improvements in these indicators given that construction likely disrupted water supply to a considerable extent in the treated areas, and because the system was not really operating as designed at the time of mid-line data collection. The signal on pressure and billed water consumption is most clear, suggesting that the network was performing more efficiently during water distribution, and delivering additional water to households. Second, for these WNP outcomes in particular, there is evidence of spillovers within Zarqa, as demonstrated by the increased significance and larger coefficients for many of these water supply changes (and also in service disruptions) when using the matched clusters in Amman as controls. Such spillovers might occur if, for example, the utility responded to better network performance in improved zones by re-distributing additional (saved) water to unimproved areas. In contrast, there is no evidence of spillovers from the WWNP. This is intuitive since the sewer expansion has primarily local effects in the newly served areas. Third, there are no consistent and statistically meaningful changes in the perceived safety of utility water or in non-network water expenses. These two findings are complementary and suggest that households consider shop water to be safer to drink (as indicated by baseline data and the findings of Orgill-Meyer et al. (2018)). We have additional corroborative evidence that households in our sample in Zarqa were no more likely to recognize behavior change messages that were disseminated as part of the WSH campaign about the need for water conservation and safe water handling than households in Amman.[13] Finally, the areas targeted by the Wastewater Network Project (WWNP) have significantly higher sewer connection rates and report decreased incidence of sewer backups. There are no clear impacts on pit emptying costs, but this outcome likely takes longer to materialize.

Importantly, the attrition of households from the sample is unrelated to sample status, as shown by the lack of significance for the DiD estimates in the final row of Table 8. Inclusion of household fixed effects changes none of the estimated coefficients, though statistical

[13] More specifically, randomly-selected promotional materials (pamphlets, posters, water toolkit, water bottle) that were used in the Water Smart Home behavior-change campaign were shown to a subsample of households in Amman and Zarqa. Only 7% of households in Zarqa reported seeing something like them, and 4% said they recognized the precise messaging material, in contrast to 11% and 6% in Amman. On the other hand, recognition of specific messages used in other campaigns in Jordan or in other countries was 7% and 11% in Zarqa and Amman, respectively. When assessing recall, messages from different sources were presented in a randomized order, and the source was not described to respondents.

significance is diminished in a few cases, likely due to reduced sample size. Dropping matched control and treatment areas that were contaminated due to expansion of the WWNP infrastructure works has no meaningful effect on the results. These estimates are also robust to inclusion of controls.[14]

6.2. Impacts on farms

The second set of results of our analysis of impacts concern the farms in different sample areas; these are summarized in Table 9. Once again, four main messages emerge from these results. First, farmers who are most subject to efforts to move away from freshwater sources of irrigation water, in the North and mid-North areas, are seen to increase their use of groundwater, while those in the mid-South and highlands move out of groundwater. These shifts are large relative to baseline use of groundwater (only about 3% overall) and consistent with the idea that water scarcity is increasing in the north JV and decreasing in the other zones. Groundwater is more costly to obtain than surface water because of the need to pump, but it is also more reliable and can be used on demand to smooth shortfalls. Higher scarcity may also reflect poor water quality relative to existing uses. In the short term, farmers in the north suffer when water supplies become more saline, because they depend more heavily on salinity-sensitive crops like citrus trees. In contrast, salinity is not such a concern for farmers along the Zarqa River and in the Middle and South JV, who mostly grow salinity-tolerant fodder, field crops and vegetables.

Second, perceptions of water quality largely align with the need for adaptation: Farmers in the north report declines in water quality (a decline of 0.3 to 0.9 points on a ten-point scale), while those in the south and highlands see improvements (by 0.6 to 0.9 points). Water quality perceptions are likely closely correlated with water availability. The larger change in the JV2 zone is also consistent with the fact that most of the expansion of wastewater reuse is currently taking place in that zone, owing to new non-JC conveyance infrastructures being

[14] We included the following controls: Household expenditures, income, a normalized asset index, baseline water supply (days/month), indicator variables for home ownership and sharing of meters, and baseline practice of in-home water treatment.

built in Jordan. Third, these water quality perceptions and expectations align with shifting cropping decisions and choices. That is, in the north we observe a decline in farming activities (by 17-32%) and a shift towards vegetables and away from salinity-sensitive citrus trees, while farming activity is broadly increasing in the Middle Jordan Valley (by 13-21%), where farmers have already adapted and vegetables and field crops are now ubiquitous. Finally, and again consistent with these patterns and especially the significant movement out of production, farmers in the Northern areas report significant and substantial reductions in profit, in contrast to those towards the south and in the highlands who report increases.

Attrition of farms from the sample (only 12 of 551 farms in all were lost) is unrelated to sample status. Inclusion of farm fixed effects changes none of the estimated coefficients, or their statistical significance, and results are once again robust to inclusion of controls.[15] The results are also broadly consistent with a systems-based water balance, which predicts that supply of treated wastewater to farms in the Jordan Valley should increase by about 10 million cubic meters due to the Compact, and by much more due to population growth and greater wastewater treatment in the As Samra Treatment Plant (Jeuland et al. 2017).[16] The latter (10 mcm/yr) amount alone represents about 15% of the freshwater supply to irrigators in the JV, and a 10% increase in the flow of treated wastewater to the Valley (Kelpsaite 2015). It seems plausible that a substitution of this magnitude is accelerating the shift in cultivation and profit patterns that we observe.

7. Discussion

This paper presented a quasi-experimental analysis of short-term impacts of a major urban water infrastructure improvement implemented in the Zarqa Governorate in Jordan. It contributes to a relatively small literature on the economic benefits of investments in water

[15] For the agricultural outcomes, we included the following controls that may relate to water use and farm productivity: Farm area, use of greenhouses, tractor ownership, farmer wealth, access to capital, and use of pumps.
[16] Thus far, the model has mainly been used for predictive purposes. Data collection on flow allocations to various locations is ongoing to validate these predictions.

and sewer systems, which represent one of the most important quasi-public goods provided by governments in low- and middle-income countries. Though we only consider short term results that also potentially overlap with disruptions in services due to construction, we find clear evidence that improvements in the water network led to improvements in water pressure and reductions in service disruptions, and more tentative evidence (based on comparisons to households in neighboring Amman) that the continuity of water supply may have improved. We also found that investments in sewerage increased the number of household connections and reduced the incidence of sewer backups. These and other changes appear to be contributing to considerable increases in flows of treated wastewater to irrigators in the Jordan Valley, flows which appear to be inducing a shift (that is costly at least in the short term) in cultivation patterns away from water-intensive and salinity-sensitive citrus trees, and into vegetables. Nonetheless, we found no evidence that the increased diversion of water to urban areas has led to savings on expenses for high cost non-network water, particularly from water shops. The lack of evidence for this secondary substitution effect may indicate that such behavioral changes take longer to manifest, or may indicate that households are skeptical of the safety of drinking water from the piped network.

These short-term results are consistent with a large literature that emphasizes the potential lack of substitutability across water sources that arises from quality differences (Orgill et al. 2013, Jeuland et al. 2016). They are also consistent with baseline surveys among households in our sample, which highlighted low confidence in the quality of water from the utility network, and low willingness to pay for improved water reliability (Orgill-Meyer et al. 2018). Ultimately, such a lack of substitutability may reduce the realized benefits of the investments of the JC, and may perpetuate a low-equilibrium trap that often plagues water utilities in developing countries. Because consumers do not trust in the quality of water from the piped water system, they may resist paying tariffs that allow full cost-recovery, or engage in theft from the water network, thereby compromising the utility's ability to invest in long-term maintenance and systems that improve reliability, and leading to accelerated depreciation of investments. Only time will tell whether the improvements in Zarqa are able to create sufficient momentum to avoid such a situation. Nonetheless, the utility and policy-makers should perhaps invest in efforts to convince households of the safety of water obtained from the network, especially since evidence suggests that this water may in fact be safer than the more expensive water that is purchased from shops in the city.

Given uncertainty over the long-term performance of these investments and the possibility of a continued evolution in beneficiary behavior, it is also critical to continue monitoring the effects of the JC in the future. This study only covers very short term midline outcomes, from a limited set of data collection activities. In the future, research should verify the persistence of the short-term changes and distributional effects. For example, farmers in the North JV will likely adjust to the shift in water supply over time, and may eventually reap benefits from a shift to vegetable cultivation, mimicking the trends already apparent in the Middle and South JV. Households may gain confidence in the quality of network water, or may persist in purchasing more expensive shop water. In addition, data from small businesses, water vendors, and the utility should be included to obtain a more complete picture of the impacts of the investment. Several issues related to each of these merit special mention at this time. First, far fewer enterprises (~30%) had water connections at baseline than households (~99%) in our sample (see Appendix Table C3 and Figures C1), primarily due to the reported connection cost (Figure C2). The latter obstacle is unlikely to have changed as a result of the obstacle, but the lack of affordable connections for enterprises makes these much more vulnerable to high water prices from alternative sources. Second, the WNP of the JC was primarily aimed at reducing the physical water loss fraction within non-revenue water, but it may also reduce administrative losses through meter replacement. Meter testing on a small sample of meters in survey areas conducted prior to this replacement meanwhile indicated 25% under-registration of consumption on average (results available upon request from the authors). It is well known that the accuracy of mechanical meters deteriorates in intermittent systems, as a function of age, water pressure fluctuations, and the presence of air in the network. As such, the JC may reduce NRW in the short term (until these new meters become degraded) by improving the accuracy of water bills. Finally, and related to the latter point, it is possible that the water utility in Zarqa may capture many of the benefits of the improvements, through higher bill collection due to improved meter accuracy, reduced maintenance costs, or by reallocating water to avoid complaints in high leakage areas. All of these issues deserve careful attention as the analysis of the JC's effects continues. Tracking these various changes will produce insights that should be relevant for many water-constrained countries in the Middle East and in other settings.

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Tables and Figures

Table 1. Summary of the JC impact evaluation components

Impact evaluation component	Data collection elements	Considered in this paper
Component 1: Impacts on beneficiaries in Zarqa	-Longitudinal households surveys in urban Zarqa Governorate & East Amman (4 waves) -Longitudinal enterprise surveys in Zarqa and East Amman (2 waves) -Cross-sectional, endline survey of water vendors in Zarqa and East Amman -Cross-sectional, endline survey of refugees who settled in Zarqa and East Amman during the JC -Qualitative endline work with Water Smart Homes infrastructure support beneficiaries and implementing plumbers	**-Yes, using 2 waves** -No, not yet complete[1] -No, not yet complete -No, not yet complete -No, not yet complete
Component 2: Impact of the primary water substitution (enhanced wastewater reuse and freshwater allocation to urban areas)	-Longitudinal farm surveys along Zarqa River & in Jordan Valley (3 waves) -Systems-based water balance analysis	**Yes, using 2 waves** **Yes, but not in detail**
Component 3: Utility-level impacts	-Longitudinal water meter testing (2 waves) -Analysis of longitudinal spatially-resolved maintenance records -Comparative tracking of utility indicators	No, not yet complete[1] No, not yet complete No, not yet complete

[1] For each of these elements, we have collected baseline data, to which we refer to a limited degree in the discussion of our results.

Table 2. Pre-matching descriptive statistics for Census blocks

Variable	Comparison with Zarqa controls				Comparison with Amman controls			
	Area A Both (N=104)	**Area B WWNP only (N=115)**	**Area C WNP only (N=524)**	**Area D Controls (N=1303)**	**Area A Both (N=104)**	**Area B WWNP only (N=115)**	**Area C WNP only (N=524)**	**Area D Controls (N=1386)**
Wealth index	-0.54***	-1.13	-0.77***	-1.21	-0.54***	-1.13***	-0.77***	0.37
Marital status – head (%)	91.0***	90.8***	87.2	88.2	91.0***	90.8***	87.2	87.7
Male head of household (%)	91.6***	92.4***	89.3***	90.3	91.6***	92.4***	89.3	89.8
Head > Secondary educ. (%)	45.3***	36.8	42.8***	38.1	45.3***	36.8***	42.8***	53.4
Average residency (yrs.)	14.2***	16.7	16.7**	16.2	14.2***	16.7***	16.7***	13.0
Non-Jordanian (%)	6.2*	7.7	4.9***	8.4	6.2	7.7	4.9***	7.6
# buildings in block	39.0	49.1***	34.3***	39.5	39.0***	49.1***	34.3***	30.6
Population density (per hA)	66.6***	72.2***	266.1**	238.4	66.6***	72.2***	266.1***	177.4
Paid employee – head (%)	78.6*	78.6*	79.7	80.6	78.6*	78.6*	79.7***	76.5
# households in block	70.6***	89.8*	85.3	83.1	70.6***	89.8	85.3***	92.3
Handicap (%)	5.6	5.6	6.2	5.9	5.6**	5.6**	6.2***	4.8

*Notes: Statistically meaningful differences are indicated by the following: *** indicates p<0.01; ** p<0.05; *; p<0.1.*

Table 3. Post-matching descriptive statistics for selected Census blocks

Variable	Comparison with Zarqa controls: Area A Both	Area A Controls	Area B WWNP only	Area B Controls	Area C WNP only	Area C Controls	Comparison with Amman controls: Area A Both	Area A Controls	Area B WWNP only	Area B Controls	Area C WNP only	Area C Controls
Wealth index	-0.25	-0.66	-0.94	-1.04	-1.08	-1.09	-0.25	-0.66	-0.94	-1.04	-1.08	-1.09
Marital status – head (%)	89.1	89.3	89.5	87.7	88.4	88.3	89.1	89.3	89.5	87.7	88.4	88.3
Male head of household (%)	90.1	89.8	90.1	90.3	90.2	90.1	90.1	89.8	90.1	90.3	90.2	90.1
Head > Secondary educ. (%)	51.4	47.2	40.0	38.3	39.3	38.6	51.4	47.2	40.0	38.3	39.3	38.6
Average residency (yrs.)	15.9	15.9	16.7	17.2	16.3	16.7	15.9	15.9	16.7	17.2	16.3	16.7
Non-Jordanian (%)	4.1	4.3	3.7	4.7	5.1	5.0	4.1	4.3	3.7	4.7	5.1	5.0
# buildings in block	35.1	37.6	38.1**	45.6	36.1	36.0	35.1	37.6	38.1**	45.6	36.1	36.0
Population density (per hA)	98.4	118.2	113.5	160.2	278.6	251.7	98.4	118.2	113.5	160.2	278.6	251.7
Paid employee – head (%)	80.3	77.8	81.5	81.4	80.9	80.3	80.3	77.8	81.5	81.4	80.9	80.3
# households in block	79.3	77.0	83.7*	96.2	81.6	83.6	79.3	77.0	83.7*	96.2	81.6	83.6
Handicap (%)	4.5	5.2	5.7	6.7	6.2	6.2	4.5	5.2	5.7	6.7	6.2	6.2

*Notes: Statistically meaningful differences are indicated by the following: *** indicates p<0.01; ** p<0.05; *; p<0.1. Matching was conducted using 1-1 nearest neighbor matching with replacement. The first stage was specified as a logit model using all of the characteristics shown above.*

Table 4. Pre-intervention trends in water consumption (all in m^3) for matched sample areas

	Comparison with Zarqa controls: Area A Both		Area B WWNP only		Area C WNP only		Comparison with Amman controls: Area A Both		Area B WWNP only		Area C WNP only	
Variable	Δ	(se)	Δ	(se)	Δ	(se)	Δ	(se)	Δ	(se)	Δ	(se)
Quarter 1 consumption	1.11	(0.99)	0.48	(0.92)	0.55	(0.80)	0.43	(1.16)	0.62	(0.92)	0.91	(1.63)
Quarter 2 consumption	-0.53	(1.18)	-0.85	(1.21)	-0.67	(1.22)	0.36	(0.88)	2.02*	(1.06)	1.89*	(1.03)
Quarter 3 consumption	-1.11	(1.00)	-0.68	(1.12)	-2.02*	(1.16)	-2.1**	(0.95)	0.00	(0.94)	0.60	(0.99)
Quarter 4 consumption	0.66	(1.37)	-0.01	(1.68)	-0.19	(1.29)	1.71	(1.23)	1.43	(1.14)	1.96	(1.24)
Annual consumption	0.13	(2.21)	-1.07	(3.23)	-2.33	(2.64)	0.41	(2.64)	4.07	(2.88)	5.36*	(3.18)

Table 5. Household survey descriptive statistics – Demographic, socio-economic, water-related, and health status variables

	Overall sample			Zarqa sample		
Variable	**N**	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**
Demographic variables						
Household Size	3359	4.91	(2.05)	2259	4.91	(2.03)
Female head of household	3359	0.15	(0.36)	2259	0.14	(0.35)
Age of head of household (in yrs)	3322	50.1	(14.0)	2247	49.9	(13.9)
Jordanian	3359	0.93	(0.25)	2259	0.93	(0.26)
Socio-economic status						
Respondent is literate	3359	0.91	(0.29)	2259	0.91	(0.29)
Average years of adult education	3359	10.6	(3.45)	2259	10.6	(3.33)
Respondent understood survey well (enumerator rating)	3359	0.87	(0.33)	2259	0.87	(0.34)
Homeowner	3359	0.73	(0.44)	2259	0.74	(0.44)
Area of home (m^2)	3359	247	(2843)	1909	250	(2934)
Home is an apartment/flat	3359	0.55	(0.50)	2259	0.56	(0.50)
Total expenditure (JD/month)	3272	450	(341)	2191	429	(297)
Total income (JD/month)	3214	426	(351)	2152	409	(303)
National Aid Fund recipient	3351	0.027	(0.16)	2253	0.026	(0.16)
Own washer	3359	0.98	(0.14)	2259	0.98	(0.13)
Own computer	3359	0.45	(0.50)	2259	0.44	(0.50)
Own air conditioner	3359	0.20	(0.40)	2259	0.22	(0.41)
Own vehicle	3359	0.45	(0.50)	2259	0.43	(0.450)
Have a home business	3359	0.039	(0.19)	2259	0.037	(0.19)
Took out a loan in the past year	3359	0.20	(0.40)	2259	0.21	(0.41)
Enumerator rating of wealth (5 point scale)	3359	2.78	(0.86)	2259	2.75	(0.84)
Anthropometrics and health measures						
Mean upper arm circumference	707	10.2	(6.46)	461	9.94	(6.43)
Skinfold thickness	707	4.73	(5.58)	461	4.58	(5.88)
# of HH members w/diarrhea, past 2 wks.	3359	0.15	(0.53)	2259	0.15	(0.56)
# of HH members w/other water-related illness	3348	0.048	(0.21)	2253	0.050	(0.22)
Water sources and reliability						
Subscribed to utility water	3359	0.97	(0.18)	2259	0.96	(0.18)
Subscribed to utility wastewater services	3245	0.79	(0.41)	2179	0.81	(0.39)
Share a water meter	3174	0.39	(0.49)	2128	0.39	(0.49)
Able to show a water bill	3219	0.39	(0.49)	2160	0.41	(0.49)
Report using water from any non-network source	3359	0.44	(0.50)	2259	0.42	(0.49)
Use water from water shops	3359	0.38	(0.49)	2259	0.37	(0.48)
Use water from tankers	3359	0.036	(0.19)	2259	0.042	(0.20)
Amount of network water used (m^3/month)	2550	7.73	(6.34)	1749	7.64	(6.14)
Amount of non-network water used (m^3/month)	3359	0.38	(1.33)	2259	0.33	(1.25)
Change amounts of water used in other seasons	3350	0.34	(0.48)	2253	0.35	(0.48)
Reported experiencing water shortage	3343	0.23	(0.42)	2247	0.29	(0.45)
Days in average month receiving water	3156	9.17	(7.09)	2138	8.33	(6.34)
Had complaints about WAJ service	3245	0.19	(0.39)	2179	0.23	(0.42)
Water & hygiene behaviors						

Treats water currently	3359	0.35	(0.48)	2259	0.38	(0.49)
Had treated water on hand	3359	0.34	(0.47)	2259	0.36	(0.48)
If treating, stores treated water 1 day or less	1300	0.90	(0.30)	918	0.91	(0.29)
Sanitation status & behaviors						
Has a private toilet	3359	0.76	(0.43)	2259	0.77	(0.42)
Toilet not connected to sewer system	3359	0.24	(0.43)	2259	0.23	(0.42)
Sanitation situation: 1=Excellent, 5=very poor	3218	2.83	(1.17)	2191	2.90	(1.16)
Water-related perceptions						
Remember hearing water/sanitation message	3359	0.48	(0.50)	2259	0.42	(0.49)
Believe diarrhea can be prevented	3319	0.71	(0.46)	2240	0.70	(0.46)
Perceived safety of utility water (0=not at all, 10=complete)	3359	5.12	(3.22)	2259	4.88	(3.26)
Perceived safety of home drinking water (0=not at all, 10=complete)	3359	8.18	(2.00)	2259	8.11	(2.05)

Table 6. Household expenses on water and wastewater, and related coping costs (all in JD/month)

	Overall sample			Zarqa sample		
Variable	**N**	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**
Expenses on network water	2851	6.16	(8.20)	1928	5.80	(8.06)
Water-related expenses / coping costs						
Expenses on non-network water	3359	6.51	(12.63)	2259	6.48	(12.93)
Value of collection time	3359	0.18	(0.37)	2259	0.18	(0.37)
Water treatment costs	3359	1.97	(4.19)	2259	2.15	(4.29)
Expenses on in-house water repairs	3359	1.46	(4.31)	2259	1.52	(4.33)
Storage costs	3359	1.38	(3.48)	2259	1.43	(3.64)
Total water-related coping costs	**3359**	**11.5**	**(13.79)**	**2259**	**11.8**	**(14.1)**
Wastewater-related expenses / coping costs						
Expenses on pit emptying	3359	3.20	(6.35)	2259	3.00	(6.25)
Toilet infrastructure costs	3359	6.47	(3.46)	2259	6.50	(3.48)
Time costs for using sanitation	3359	0.22	(1.43)	2259	0.11	(0.99)
Total wastewater-related coping costs	**3359**	**9.88**	**(7.33)**	**2259**	**9.61**	**(9.08)**

Notes: When billing information for network water from the prior period was not available, network water expenses were estimated using self-reports from the most recent quarter. If households reported water bill amounts, those were used. If households reported quantities but not bill amounts, the bill was estimated using the known water tariff structure in Zarqa.

Table 7. Farmer survey descriptive statistics (Demographics, farm socioeconomic characteristics, inputs, and outputs)

Variable	N	Mean	(SD)	N	Mean	(SD)
Demographic variables						
Age	548	52.1	(12.7)			
Married	550	0.95				
Farmer training	550	0.03				
Jordanian	550	0.94				
Basic Farm information						
Area of land	550	37.6	(34.7)			
Area cultivated	550	32.3	(27.1)			
Market value of land (thousands of JD)	469	166.7	(125.3)			
Own farm	550	0.50				
Grow crops in winter	550	0.80				
Grow crops in summer	550	0.40				
Socioeconomics and assets						
Total HH consumption/month (JD)	550	892	(750)			
Total HH income/month (JD)	550	1297	(1577)			
Total value of assets ('000 JD)	550	22.4	(29.3)			
Value of water-related assets ('000 JD)	550	7.19	(7.32)			
Have greenhouse	550	0.20				
Own tractor	550	0.14				
Own transport vehicle	550	0.32				
Own plough	550	0.11				
Enumerator opinion of wealth (1=very poor; 5=rich)	550	3.13	(0.90)			
Inputs‡	*Winter / overall*			*Summer*		
Vegetables: Total ('000 JD)	441	9.63	(15.0)	221	2.84	(8.17)
Field crops: Total ('000 JD)	441	0.38	(1.52)	221	0.30	(1.53)
Trees: Total ('000 JD)	441	3.25	(7.00)	221	3.23	(9.11)
Flowers: Total ('000 JD)	441	0.20	(2.63)	221	0.22	(1.31)
Number of permanent workers	550	1.55	(2.42)			
Outputs/revenues‡	*Winter / overall*			*Summer*		
Vegetables: Output (tons)	441	76.0	(139)	221	16.1	(44.5)
Field crops: Output (tons)	441	26.5	(341)	221	7.85	(37.0)
Trees: Output (tons)	441	28.5	(102)	221	34.0	(53.8)
Flowers: Output (tons)	441	0.00	(0.048)	221	0.00	(0.00)
Total revenue (calculated, in '000 JD)	441	23.6	(52.3)	221	8.86	(27.8)
Constraints (1=excellent; 5=very poor)	*Both Seasons*					
Soil fertility	550	2.29	(0.79)			
Irrigation water amount	550	3.05	(1.06)			
Irrigation water quality	550	2.81	(1.09)			
Input costs	550	3.52	(0.91)			
Access to capital	550	3.00	(0.84)			
Access to markets	550	2.92	(0.96)			
Water supply characteristics	*Winter / overall*			*Summer*		
Planned water (m^3)	441	13893	20503	221	5052	7482
Actual water (m^3)	441	17559	25854	221	6846	9647
Average water quality (1=excellent, 5=very poor)	441	2.95	0.95	221	2.58	0.85
Water sufficiency	550	0.36				

Have drip irrigation	550	0.76				
Use pumps	550	0.25				
Use groundwater	550	0.03	0.18			
Have water quality problems	550	0.49	0.50			
Amount paid for water each year	550	479	1249			

‡ *Inputs and revenues are only reported for farms with activity in that season, hence the smaller sample sizes for these statistics.*

Table 8. Difference-in-differences results for households

	Compared to Zarqa controls						*Compared to Amman controls*					
Outcome	**WNP**		**WWNP**		**Both**		**WNP**		**WWNP**		**Both**	
Hrs/wk of water supply.	-0.34	(0.64)	-0.47	(0.67)	-0.90	(0.68)	0.34	(0.53)	**0.92****	(0.43)	0.79	(0.56)
Days/wk of water supply	1.13	(0.74)	-0.62	(0.90)	-0.34	(0.78)	**3.3*****	**(0.91)**	1.7	(1.0)	-0.60	(0.95)
Billed consumption (m^3/yr)	**9.5****	**(4.60)**	-6.27	(8.97)	**11.1****	**(4.37)**	Not yet available					
Expenses on non-network water (JD/month)	0.97	(1.10)	0.95	(1.41)	-0.59	(1.50)	-1.62	(1.17)	1.49	(1.52)	**2.91***	**(1.50)**
Perceived safety of water (10-pt scale)	0.29	(0.30)	-0.22	(0.32)	0.12	(0.30)	0.50	(0.32)	-0.41	(0.32)	0.16	(0.32)
Pressure of water is poor (5-pt scale)	**-0.52*****	**(0.15)**	-0.21	(0.15)	**-0.79*****	**(0.14)**	**-0.44*****	**(0.13)**	-0.033	(0.12)	**-0.70*****	**(0.12)**
Service disruption	0.02	(0.03)	0.03	(0.04)	**0.08****	**(0.04)**	**-0.08*****	**(0.02)**	**-0.08*****	**(0.03)**	**-0.06***	**(0.03)**
Have sewer connection	0.03	(0.02)	**0.07****	**(0.03)**	0.05	(0.04)	0.03	(0.03)	**0.08****	**(0.04)**	0.02	(0.04)
Sewer backup	0.02	(0.03)	**-0.03***	**(0.02)**	0.00	(0.01)	0.01	(0.01)	**-0.03***	**(0.016)**	0.02	(0.01)
Pit emptying cost (JD/month)	-4.9	(3.9)	3.8	(4.0)	-1.7	(4.3)	-3.7	(4.6)	3.2	(7.5)	-0.40	(8.5)
Lost to follow-up	-0.00	(0.03)	0.02	(0.03)	0.04	(0.03)	0.01	(0.02)	-0.03	(0.03)	0.01	(0.02)

*Notes: Reported coefficients are for the interaction of a dummy for each area and an indicator for the third round household survey (coefficient κ in equation 1). Standard errors, clustered at the level of the sampling unit, are shown in parentheses; * $p<0.1$ ** $p<0.05$ *** $p<0.01$. Billed consumption is from utility records, not from the survey. Nearly all results are unchanged with inclusion of household-specific fixed effects, and results are robust to dropping contaminated blocks.*

Table 9. Difference-in-differences results for the agricultural survey

Outcome	JV1: North		JV2: North-Mid		JV3: Mid-North		JV4: Mid-South		Highlands	
Use any groundwater	**0.04***	**(0.02)**	**0.05****	**(0.02)**	-0.01	(0.02)	**-0.05****	**(0.02)**	**-0.04***	**(0.02)**
Water quality rating (10-pt scale)	-0.31	(0.31)	**-0.91*****	**(0.31)**	-0.49	(0.31)	**0.88*****	**(0.31)**	**0.65****	**(0.31)**
Grew in summer	**-0.21*****	**(0.07)**	**-0.32*****	**(0.07)**	**0.19*****	**(0.07)**	**0.19*****	**(0.07)**	**0.20*****	**(0.07)**
Grew in winter	**-0.28*****	**(0.06)**	**-0.17****	**(0.07)**	**0.21*****	**(0.07)**	**0.13***	**(0.07)**	0.08	(0.07)
Grew vegetables	0.02	(0.02)	**0.05****	**(0.03)**	-0.02	(0.03)	-0.02	(0.03)	**-0.04***	**(0.02)**
Grew trees	-0.02	(0.02)	-0.05	(0.05)	0.06	(0.06)	0.09	(0.05)	-0.08	(0.05)
Total profits ('000 JD)	**-19.7*****	**(6.8)**	**-14.5****	**(6.3)**	**9.96****	**(4.93)**	2.27	(5.11)	**9.08***	**(4.86)**

*Notes: Reported coefficients are for the interaction of a dummy for each area and an indicator for year 2. Standard errors, clustered at the level of the pump station, are shown in parentheses; * p<0.1 ** p<0.05 *** p<0.01. Nearly all results are unchanged with inclusion of controls, or farm-specific fixed effects. Saturated model including all areas yields similar, but stronger, results.*

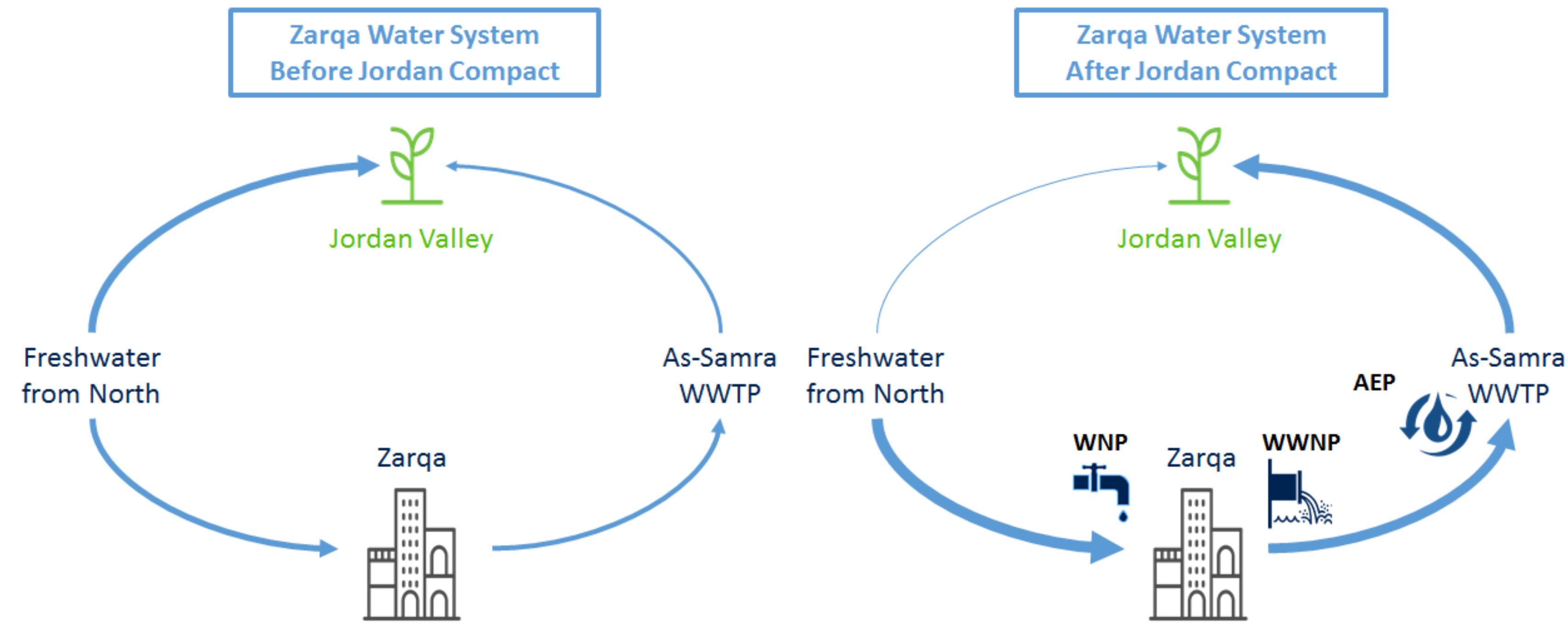


Figure 1. Conceptual representation of the logic behind the primary substitution effect of the Jordan Compact (Note: Arrows are not drawn to scale of expected impact).

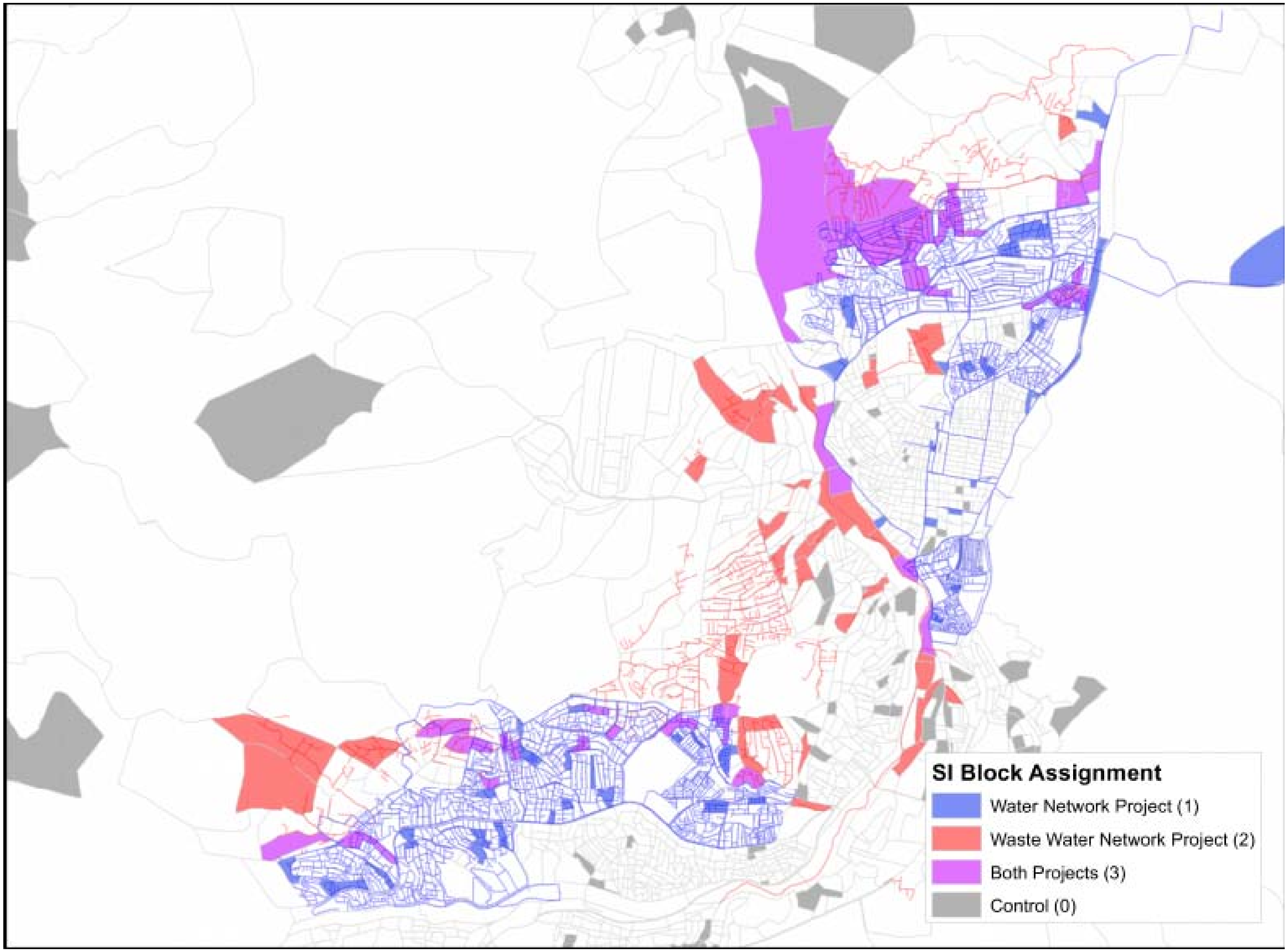


Figure 2. Map of treatment and control blocks and infrastructure works, with rehabilitated water pipes in blue and new wastewater networks shown in red (Note that some areas are off the map and therefore not shown, e.g. all controls in Amman, and some in Zarqa).

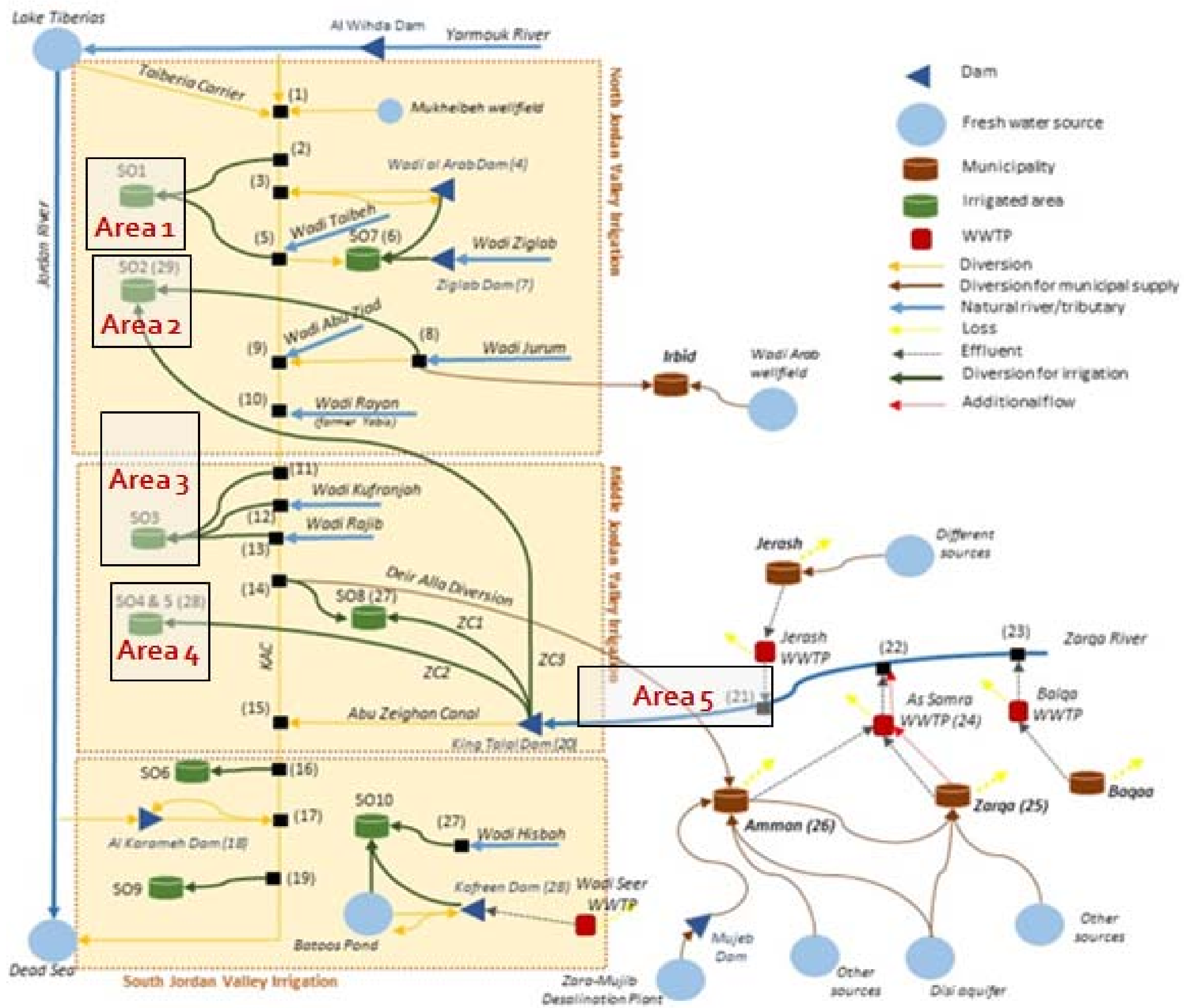


Figure 3. Schematic of water supply system for the Jordan Valley, showing freshwater sources in the North (Yarmouk River and Lake Tiberias), and blended water in the southeast (Zarqa River + wastewater treatment plants). Zones selected for farm surveys are labeled Areas 1-5.

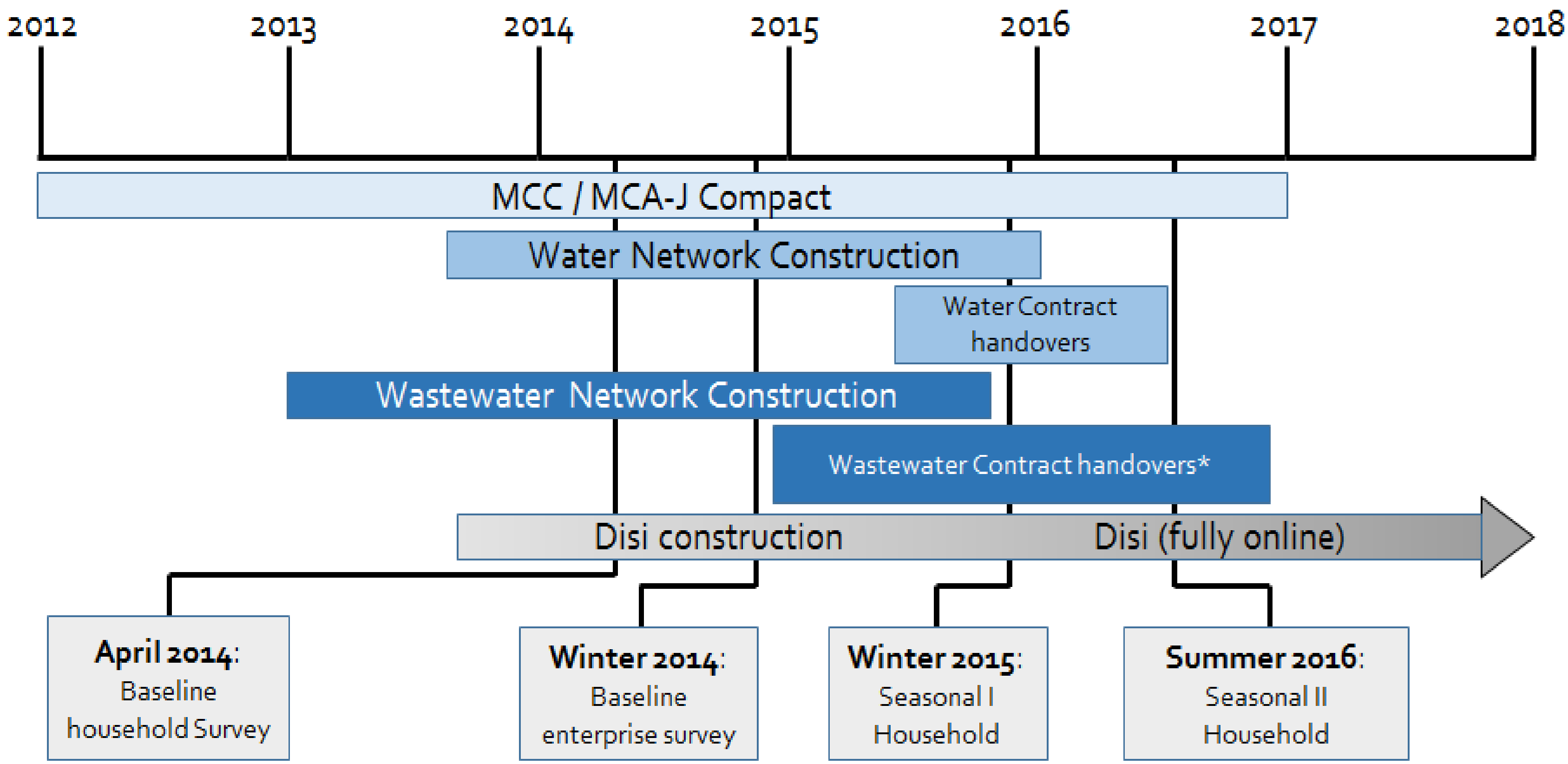


Figure 4. Timing of data collection, relative to the implementation of the infrastructure works. [Note * indicates that a small portion of the wastewater network project (10 km, out of a total of 312 km) was handed over earlier, in March 2014].

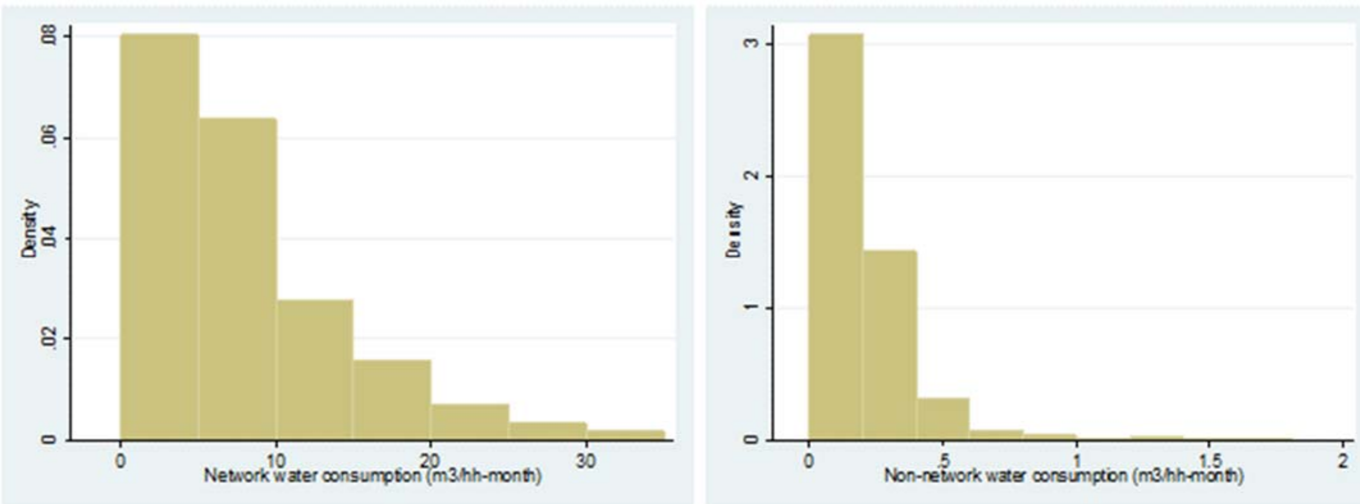


Figure 5. Distribution of monthly (left) network water amounts used and (right) non-network water amounts used *(Note the differences in the scale for the x-axis).*

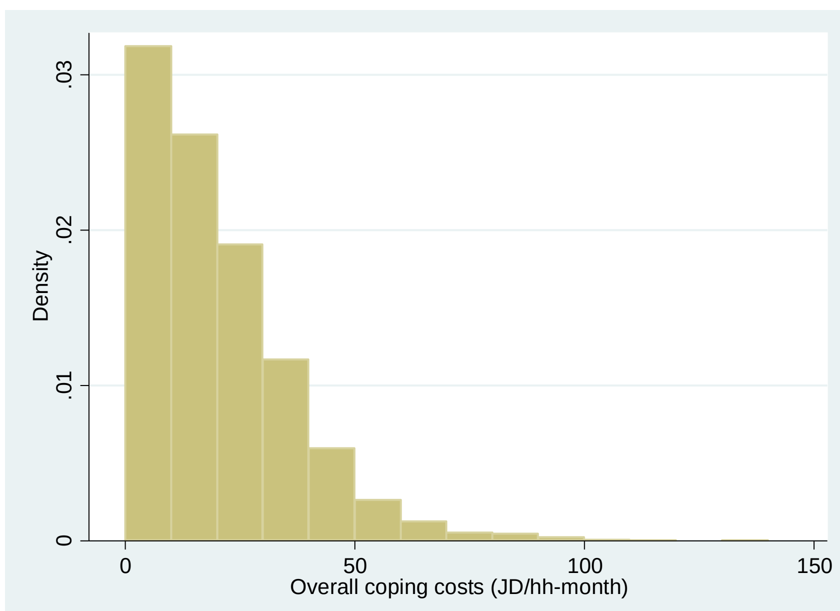
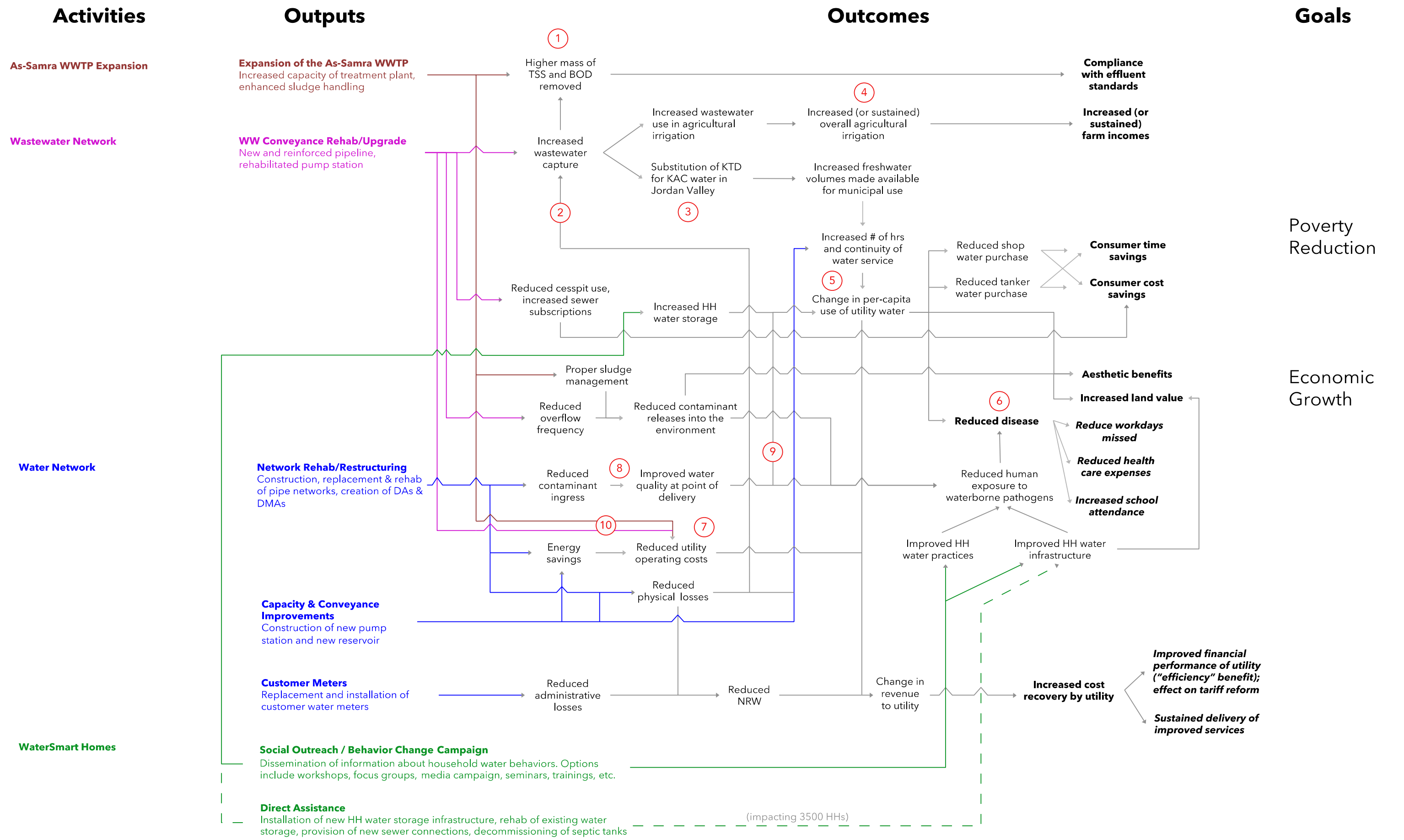


Figure 6. Distribution of total water and wastewater-related coping costs among survey households

Appendix A. Jordan Compact program logic



Key:
- Colors correspond to Activity
- Normal text corresponds to intermediate outcomes
- **Bold** corresponds to longer term outcomes
- ***Bold italic*** corresponds to secondary or derivative long term outcomes
- Numbers correspond to relationships that include caveats included below

Figure A1. Impact Logic Diagram for the Jordan Compact.

Annotation List:

1 The As-Samra Facility expansion will enable removals of suspended matter and oxygen-demanding materials from increased volumes of wastewater that would not be treated in the absence of the expansion, as well as potentially facilitating the proper management of sewage sludge. In other words, it will not affect the volume of wastewater production from Zarqa, but it will ensure that increased effluent volumes will continue to meet internationally recognized wastewater treatment standards.

2 Wastewater volume increases will result from increased wastewater capture, a product of the wastewater network rehab/upgrade. It *could* also result from reductions in physical losses from the water network, assuming that the reduction of those losses lead in turn to increased municipal water usage.

3 Measuring the specific amount of replacement of freshwater by blended water (blended = treated effluent plus freshwater from the Zarqa watershed) in the Jordan Valley or elsewhere downstream of the As-Samra Plant will require careful construction of a water balance for the system.

4 Depending on the degree of substitution taking place, the amount of water used for irrigation downstream of the As-Samra facility may remain static or actually increase. Alternatively, freshwater allocation to farmers may decline at a rate higher than the increase in blended KTR water that is made available, in which case overall irrigation may actually decline, and the Compact benefit will be in slowing the decline of irrigation.

5 Changes in per-capita water use will be influenced by 1) increased # of hours and continuity of municipal water service, 2) improved water quality at the tap, if perceived by consumers, and 3) increased HH storage infrastructure resulting from WaterSmart Homes - though this will be only from a small number of homes. However, increases in usage could be modulated by increased metering, which will change household water use behavior. (We have not indicated this modulating factor in the diagram).

6 We include multiple possible causal relationships between Compact activities and disease. The first is the result of increasing per-capita water usage, and we emphasize that the relationship between water quantity interventions and health indicators such as diarrhea are not supported by the current literature. The second is by reducing disease transmission pathways resulting from urban wastewater overflows as well as those from land application of sewage sludge at As-Samra. Finally, the Water Smart Homes activity could result in reduced pathogen exposure via improvements in hygiene behaviors as well as reduced contamination in household storage.

7 We have not made a distinction here between overall energy savings for the utility and energy savings per unit volume of water delivered. We expect unit costs to decline, but overall system utilization - and thus, energy consumed, and operating cost incurred - could actually increase.

8 Though we have not seen significant data yet, we anticipate that the changes in water quality at the tap will be minimal, since there appear to be few documented instances of fecal contamination exceeding the WHO standard in the Zarqa system.

9 Improved water quality at the tap will result in increased per-capita use of utility water only if user perceptions of utility water improve in tandem. We note that the water quality benefits are likely to be difficult to detect (since pathogen detection in utility water is already so low), so a corresponding change in customer perceptions is also of low probability.

10 We note that the expansion of the As-Samra WWTP and the rehabilitation of the Wastewater Network may add to utility operating costs considerably, perhaps more than the associated increase in wastewater treatment revenues.

Appendix B: Sample selection using propensity score matching

To select the zones for the household and enterprise surveys, we implemented ordinary propensity score matching (PSM) *ex ante*, i.e. prior to data collection. This procedure first entailed predicting the selection into the various treatment groups using logistic regression, where treatment status – defined in our case using GIS maps of the investments in the Jordan Compact – is regressed on a vector of observed pre-intervention characteristics *X* of those areas:

$$T_i = \beta X_i + \varepsilon_i, \qquad (1)$$

where T_i = 1 if unit *i* is assigned to treatment and 0 otherwise, and ε_i is an error term. We conducted PSM at the block level (the unit used by the Department of Statistics for Census sampling), using 11 variables recorded or calculated from the Census. In an effort to address the issue of spillovers, we included untreated areas both in and outside of the Zarqa water and wastewater network, by running these regressions including nearby neighborhoods from Amman. For the classification of areas into the four sample groups (WNP, WWNP, Both, None), we merged shapefiles indicating the boundaries of blocks obtained from DoS with shapefiles showing the locations of the WNP and WWNP infrastructure works obtained by project implementers and the MCA-J. Blocks treated by each project or by both projects were then identified using GIS functions that identify intersections of lines (for pipe works) and polygons (Census blocks). The pre-intervention data used for this first stage were then drawn from sources that were: a) available for our purposes; and b) derived from representative samples drawn at fairly fine geographical scale – namely block-level Census, income and expenditure survey data from Jordan's Department of Statistics (DoS). The asset lists available from DoS data sources were used to create a wealth index using principal components analysis, retaining the first principal component.

The results for the first stage logit are shown in Table B1. These regressions indicate that areas selected to receive the water network improvements tend to have fewer buildings but more households per block (i.e., higher density) than areas not receiving any Compact improvements in Zarqa, and slightly higher wealth. (Column 1). Households in these WNP areas tend to have lived at their current residence for fewer years, are more likely to be Jordanian, and are less likely to have married household heads. The areas selected for WWNP improvements in Zarqa have the opposite characteristics: lower density, more non-Jordanians, older and lower wealth residents, and a higher proportion of married household heads (Column 2). Finally, areas selected for both WWNP and WNP improvements tend to look more like WWNP areas than WNP areas (Column 3). Finally, compared to untreated zones in Amman, all three areas in Zarqa tend to be lower density, higher percentages of married household heads, and have lower wealth (Column 4-6).

Following logit estimation, we obtained the propensity score (or predicted probability of participation) for each geographic unit (Census block) in the sample:

$$p(x) = \Pr[T = 1|X = x] = \frac{e^{\beta x}}{1+e^{\beta x}} \qquad (2)$$

We then matched areas with similar propensity scores (i.e., blocks that appeared equally likely to have received specific exposures to the intervention, conditional on these observable factors) to ensure comparability across control and treated areas. We used 1-1 nearest neighbor matching with replacement and imposed a caliper of 0.02 around every match. For example, if a treatment block had a propensity score of 0.64, it could only be matched with a counterfactual block with a propensity score between 0.62 and 0.66, and the nearest match satisfying that constraint would be assigned. In most cases the nearest neighbor was retained as the match, but in a few cases the caliper rule superseded the nearest neighbor rule in order to ensure a good match for each treatment block.[1]

Finally, to verify the comparability of the matched samples, we conducted balance tests and checked the overlap in support between treatment and control groups. The final map of sample areas located in Zarqa is shown in Figure 1; we do not show the map for Amman given the difficulty of reading the map on a broader geographic scale.

There are three principle threats to the validity of estimates obtained using PSM in this way (Rosenbaum and Rubin 1983). The first is that unobserved differences between treatment and comparison may lead to biased estimates of impact when these differences are correlated with treatment outcomes (violation of the so-called Conditional Independence Assumption). Such unobserved differences may encompass for example preferences among decision-makers for a particular zone that is not reflected in the formal prioritization algorithm, or systematic differences in the preferences for improved water supply among beneficiaries of different zones. Unfortunately, we could not fully address this threat, because the parameters used in the prioritization algorithm that was used to select treatment areas for the water network improvements were only available for the treatment zones themselves, and the criteria for selection of expansion of areas treated by the wastewater network expansion were not fully transparent. To the extent that such factors were accounted for in the observable (primarily socio-economic and demographic) characteristics of the affected zones, these would be reflected in our approach.

The second threat emerges when the common support region is narrow such that the universe of treated and control areas are difficult to compare (Dehejia and Wahba 2002). This was not a major problem in our case, and we had a sufficient number of matches from which to choose. Finally, the third important threat, which is more generally applicable to a variety of evaluation

[1] In a few cases, SI also conducted manual matches to reduce the number of control blocks required in our sample. SI wanted to minimize the pool of control blocks so as to not threaten the statistical power of the evaluation. For example, if a treatment block had a propensity score of 0.3456 and the nearest neighbor match was 0.3457 and a control block matched to another treatment block from a different treatment arm had a propensity score of 0.3460, we would manually choose the latter block to match with the current treatment block. The rationale for this will be discussed in more detail further below.

estimators, emerges from violation of the Stable Unit Treatment Value Assumption (SUTVA), which requires that treatment does not indirectly affect untreated units (i.e. no spillovers). Our strategy of sampling from neighboring blocks in Amman was utilized specifically to deal with this issue.

Table B1. Results of first-stage logit model for matching

	ZARQA CONTROLS						AMMAN CONTROLS					
Variable	Area A Treat WNP		Area B Treat WWNP		Area C Treat Both		Area A Treat WNP		Area B Treat WWNP		Area C Treat Both	
Population density ('000/hA)	0.00	(0.000)	-0.00***	(0.000)	-0.00***	(0.001)	0.00***	(0.000)	-0.00***	(0.001)	-0.00***	(0.001)
# buildings in block	-0.01***	(0.003)	0.03***	(0.007)	0.02***	(0.007)	0.02***	(0.003)	0.02***	(0.006)	0.02***	(0.006)
# households in block ('00)	0.01***	(0.002)	-0.00	(0.004)	-0.01***	(0.004)	-0.01***	(0.001)	-0.00	(0.003)	-0.01**	(0.003)
Male head of household (%)	-0.48	(0.842)	3.03	(2.019)	-3.29	(2.037)	-2.04**	(0.883)	3.27*	(1.879)	-0.11	(1.808)
Handicap (%)	1.41**	(0.691)	-2.12	(1.736)	-0.44	(1.759)	2.53***	(0.870)	1.09	(1.674)	-0.85	(1.525)
Non-Jordanian (%)	-2.51***	(0.491)	2.93***	(1.089)	4.07***	(1.283)	-3.68***	(0.636)	1.57*	(0.846)	1.66	(1.255)
Average residency (yrs.)	-0.02**	(0.010)	0.07***	(0.024)	-0.08***	(0.021)	0.11***	(0.010)	0.09***	(0.022)	-0.02	(0.019)
Head > Secondary educ. (%)	0.40	(0.312)	-1.43**	(0.683)	0.82	(0.641)	1.29***	(0.334)	-0.26	(0.664)	0.60	(0.590)
Marital status – head (%)	-2.77***	(0.730)	4.47**	(1.906)	5.01***	(1.762)	2.11***	(0.792)	2.46	(1.669)	1.81	(1.581)
Paid employee – head (%)	0.26	(0.319)	-1.64**	(0.714)	-1.02	(0.669)	0.36	(0.336)	-0.26	(0.686)	-0.13	(0.585)
Wealth index	0.14***	(0.043)	-0.25**	(0.102)	0.06	(0.085)	-0.23***	(0.041)	-0.20**	(0.094)	-0.04	(0.079)
Constant	2.48***	(0.749)	-7.42***	(1.949)	-0.44	(1.764)	-3.00***	(0.771)	-7.64***	(1.808)	-1.77	(1.566)
N	1822		623		612		1907		542		531	
Pseudo-R^2	0.073		0.385		0.318		0.226		0.293		0.193	

*Notes: Coefficients and standard errors (in parentheses) are reported. Statistically meaningful differences are indicated by the following: *** indicates $p<0.01$; ** $p<0.05$; *; $p<0.1$. The sample size varies, because units in other treatment groups are omitted from the regressions used for matching the group in question. The wealth index is expressed as the first principal component derived from principal components analysis of the following list of assets: washing machine, solar heater, microwave, private car, mobile phone, computer, and an internet connection.*

Appendix C: Other sample and data details

Table C1. Target and actual sample size across survey rounds (household survey)

	Target sample	Actual surveyed sample		
		Baseline	**S1**	**S2 ("midline")**
Zarqa Water	539	493	495	537
Zarqa Wastewater	473	456	462	465
Zarqa Both	473	450	453	489
Zarqa Control	902	845	873	919
Amman Control	1188	1098	1133	1184
Total	3575	3359	3416	3596
Sample relative to target		94.0%	95.6%	100.6%
Cumulative loss of hhs		n.a.	649	510

Notes: Final target sample sizes varied due to quality of matches across arms. For example, controls in Amman do not match as well across arms as those in Zarqa, so more blocks were needed to maintain balance on pre-intervention observables. 707 new households were enrolled in the first seasonal survey, to replace those lost to attrition (649 households) and increase sample size.

Table C2. Selected farm survey descriptive statistics, differentiated by zone

Variable	Jordan Valley 1 (North) (n=114)		Jordan Valley 2 (North/Middle) (n=108)		Jordan Valley 3 (Middle) (n=108)		Jordan Valley 4 (Middle/South) (n=110)		Highlands (n=110)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Demographic variables										
Age	52.9	9.77	56.4	12.8	52.1	14.1	46.9	12.1	52.3	12.8
Children in hh	1.94	2.25	1.32	1.80	1.73	2.02	1.86	2.07	1.56	1.88
Adults in hh	3.34	2.90	3.48	3.48	3.64	3.15	2.90	2.33	4.25	2.88
Farmer training	0.12	0.33	0.02	0.14	0.00	0.00	0.01	0.10	0.02	0.13
Jordanian	0.98	0.13	0.97	0.17	1.00	0.00	0.79	0.41	0.97	0.16
Basic farm information										
Area of land (dunum)	34.1	8.54	37.9	11.5	37.8	13.9	36.5	11.5	41.7	74.2
Area cultivated (dunum)	32.2	8.60	35.2	10.8	32.1	13.1	28.3	12.3	33.8	56.1
Market value of land ('000 JD) ‡	146.9	57.5	179.2	88.7	189.6	94.0	131.1	108.5	189.3	229.1
Own farm	0.59	0.49	0.56	0.50	0.46	0.50	0.23	0.42	0.64	0.48
Manage farm for others	0.00	0.00	0.21	0.41	0.01	0.10	0.08	0.28	0.02	0.13
# of buildings on farm	0.81	0.83	0.80	0.93	1.04	0.86	0.85	0.81	0.72	1.13
Grow crops in winter	0.61	0.49	0.71	0.45	0.95	0.21	0.98	0.13	0.75	0.43
Grow crops in summer	0.50	0.50	0.51	0.50	0.25	0.44	0.32	0.47	0.43	0.50
Socioeconomic status										
Wealth stairway (1 to 6; 6=richest)	3.16	1.12	3.71	1.24	3.11	0.93	3.33	0.94	3.31	0.96
Wealth stairway in 4 years ‡	2.82	1.13	3.56	1.07	3.68	1.03	3.73	1.09	3.29	0.99
Total HH consumption (JD/mo)	648	414	1303	1293	898	643	872	458	754	390
Total HH income (JD/mo)	987	1052	2379	2805	1105	986	1149	912	893	621
Total value of assets ('000 JD)	8.39	9.35	12.7	12.6	40.6	41.5	39.7	33.5	11.5	15.2
Value of water assets ('000 JD)	4.88	4.50	7.68	8.36	7.89	6.41	9.57	6.88	6.05	8.91
Have greenhouse	0.02	0.13	0.03	0.17	0.50	0.50	0.43	0.50	0.04	0.19
Own tractor	0.08	0.27	0.23	0.42	0.15	0.14	0.15	0.35	0.08	0.28
Own transport vehicle	0.24	0.43	0.17	0.37	0.36	0.48	0.54	0.50	0.31	0.46
Own cooling equipment	0.00	0.00	0.03	0.17	0.01	0.10	0.01	0.10	0.01	0.10
Own plough	0.09	0.28	0.06	0.23	0.08	0.28	0.18	0.39	0.13	0.33
Saved in past year	0.25	0.43	0.17	0.37	0.02	0.14	0.18	0.39	0.13	0.33
Enumerator opinion of wealth (1=very poor; 5=rich)	2.92	0.90	3.48	1.07	3.11	0.81	3.16	0.92	3.00	0.68
Farm inputs										
Overall winter: Total ('000 JD)	3.85	2.46	6.72	5.70	22.8	16.5	22.1	16.1	4.92	5.47
Overall summer: Total ('000 JD)	3.97	2.59	4.84	3.20	18.8	26.6	6.13	9.31	5.15	5.54
Have permanent workers	0.57	0.50	0.58	0.50	0.82	0.38	0.69	0.46	0.53	0.50
Number of permanent workers	0.72	0.86	0.79	1.15	3.06	3.87	2.14	2.50	1.07	1.54
Total JD/year; permanent workers	2342	2635	2396	3511	7503	8055	5417	5913	3053	4532
# of workers without pay	3.60	5.10	1.28	2.25	2.50	5.40	4.77	15.0	7.85	28.6
Outputs/revenues—winter										
Overall: Area (dunum)	30.9	15.7	32.7	19.4	30.2	18.8	27.2	15.0	34.2	57.1
Vegetables: Yield	3.17	12.6	3.66	12.0	136.2	155.2	153.7	146.2	28.8	148
Field crops: Yield	7.72	23.0	1.19	4.46	0.14	1.20	65.8	673.5	47.5	163

Trees: Yield	56.7	47.6	67.3	201.5	16.8	67.6	0.33	3.09	19.7	84.3
Flowers: Yield	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.10	0.0	0.0
Last winter yield=normal ‡	0.86	0.35	0.81	0.40	0.64	0.48	0.78	0.42	0.98	0.15
Total crop value ('000 JD) ‡	11.9	9.85	7.72	48.8	46.0	64.0	56.3	63.1	62.1	128.8
Outputs/revenues—summer										
Overall: Area (dunum)	28.1	15.3	26.5	16.5	24.7	18.7	17.4	12.9	23.3	29.6
Vegetables: Yield	3.22	9.23	3.02	9.25	52.0	96.8	32.5	46.9	14.1	30.9
Field crops: Yield	1.23	6.70	1.84	8.89	0.67	2.92	5.37	14.7	28.9	75.2
Trees: Yield	60.0	46.2	57.6	53.5	7.93	24.3	0.60	3.55	14.7	66.5
Flowers: Yield	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Last summer yield=normal ‡	0.89	0.31	0.87	0.34	0.52	0.51	0.74	0.44	0.94	0.24
Total revenue ('000 JD) ‡	8.91	6.50	13.4	44.2	18.6	34.7	11.3	17.6	4.72	17.6
Constraints (1=excellent; 5=very poor)										
Soil fertility	2.10	0.56	2.06	0.66	2.56	0.96	2.63	0.89	2.12	0.63
Irrigation water amount	2.78	0.83	2.83	0.96	3.89	0.85	3.55	0.84	2.24	0.94
Irrigation water quality	2.12	0.64	2.26	0.78	3.72	0.84	3.55	1.01	2.44	0.97
Canal position	2.75	0.99	2.56	0.88	3.11	1.01	3.12	0.94	2.84	1.17
Drainage	2.49	0.66	2.60	0.67	2.80	0.76	2.94	0.84	2.63	0.69
Irrigation water situation										
Planned water ('000 m³) - winter‡	16.9	10.0	20.0	20.3	12.5	24.9	9.34	21.6	14.3	19.8
Actual water ('000 m³) - winter‡	20.2	11.5	25.6	38.4	18.8	37.4	10.2	8.48	17.2	23.2
Average water quality - winter (1=excellent, 5=very poor)	2.33	0.55	2.42	0.62	3.75	0.90	3.33	0.87	2.46	0.85
Planned water ('000 m³) -summer‡	5.05	7.38	4.96	8.01	4.34	3.37	4.44	7.55	7.10	14.2
Actual water ('000 m³) - summer‡	8.22	12.3	5.91	9.52	7.07	5.70	6.20	9.16	7.53	14.2
Average water quality - summer (1=excellent, 5=very poor)	2.32	0.61	2.11	0.66	3.73	0.97	3.29	0.83	2.26	0.85
Water sufficiency	0.43	0.50	0.36	0.48	0.06	0.23	0.16	0.37	0.78	0.41
Have spray irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.42
Have drip irrigation	0.70	0.46	0.83	0.37	0.93	0.26	0.89	0.31	0.45	0.50
Have water storage tank	0.22	0.42	0.12	0.33	0.30	0.46	0.40	0.49	0.19	0.39
Use pumps	0.04	0.21	0.08	0.28	0.32	0.47	0.47	0.50	0.35	0.48
Spending on pumps	45.7	237	59.5	210	492	1071	413	727	586	1085
Spending on network	549	788	260	395	585	650	577	758	274	352
Changed crop mix because of water shortage	0.00	0.00	0.00	0.00	0.14	0.35	0.20	0.40	0.02	0.13
Have water quality problems	0.08	0.27	0.27	0.45	0.88	0.33	0.90	0.30	0.35	0.48
Subjective water quality rating	6.24	1.43	6.22	2.28	4.40	1.62	4.08	1.68	5.95	1.92
Amount paid for water each year	337	165	485	471	630	818	897	2545	52.3	285.9
Water user association exists	0.39	0.49	0.23	0.42	0.36	0.48	0.01	0.10	0.00	0.00
Member of WUA	0.11	0.31	0.06	0.23	0.11	0.32	0.00	0.00	0.00	0.00
Effectiveness of WUA‡	2.76	0.83	2.40	0.82	2.41	0.97	2.00	.	.	.

Notes: Variables for which some observations are missing are noted by the symbol ‡. A more complete list of variables is available upon request. Inputs and revenues are only reported for farms with activity in that season, and hence have smaller sample sizes.

Table C3. Enterprise survey descriptive statistics – employee data, business owner characteristics, obstacles to growth, assets, and costs

	Full sample			Zarqa sample		
Variable	**N**	**Mean**	**(St. Dev)**	**N**	**Mean**	**(St. Dev.)**
Firm characteristics						
Sole proprietorship	345	0.87	(0.34)	281	0.87	(0.33)
General partnership company	345	0.084	(0.28)	281	0.068	(0.25)
Employee data						
Total employees	341	5.09	(11.0)	277	5.09	(11.4)
Total male employees	341	4.29	(7.89)	277	4.19	(7.86)
Total skilled full-time employees	341	2.19	(8.96)	277	2.32	(9.88)
Total unskilled full-time employees	341	1.70	(4.24)	277	1.66	(3.83)
Total unpaid workers	341	0.71	(0.58)	277	0.66	(0.57)
Avg. age of full-time, skilled workers	155	30.0	(7.44)	118	30.2	(7.93)
Business Owner Overview						
Years of owner experience	341	15.3	(10.1)	277	14.9	(10.2)
Business owner's age	341	46.3	(12.3)	277	46.3	(12.1)
Business owner's gender (1=female)	343	0.079	(0.27)	279	0.082	(0.28)
Business owner's total monthly income	151	666	(629)	124	599	(470)
Obstacles to growth (1=Not at all; 5=Very big)						
Obstacle to growth - cost of electrical service	341	3.84	(0.97)	278	3.88	(0.92)
Obstacle to growth - water quality and reliability	341	3.06	(1.19)	278	2.91	(1.15)
Obstacle to growth - cost of water supply	341	3.65	(1.15)	278	3.55	(1.16)
Obstacle to growth - insufficient demand	341	2.62	(1.08)	278	2.62	(1.06)
Obstacle to growth - inflation and price instability	341	4.35	(0.92)	278	4.27	(0.96)
Enterprise assets						
Estimated market value of property's land (‘000 JD)	197	43.9	(61.4)	150	42.8	(66.8)
Estimated market value of buildings/ structures (‘000 JD)	250	54.9	(203)	197	56.4	(224)
Made any investments in business, last yr	341	0.01	(0.09)	278	0.01	(0.10)
Business' total sales last month (‘000 JD)	271	8.56	(26.5)	230	9.35	(28.1)
Monthly enterprise costs						
Paid labor (‘000 JD)	240	1.79	(4.12)	195	1.84	(4.38)
Services (JD)	38	1.23	(2.63)	38	1.23	(2.63)
Land/building rent (JD)	278	0.97	(3.17)	224	0.89	(2.33)
Electricity (JD)	325	0.44	(1.47)	262	0.44	(1.53)
Water usage, behaviors, shortage						
Use private piped water	341	0.30	(0.46)	278	0.28	(0.45)
Use shared piped water	341	0.18	(0.39)	278	0.19	(0.39)
Use water tanker	341	0.26	(0.44)	278	0.27	(0.44)
Use water shops	341	0.43	(0.50)	278	0.45	(0.50)
Average cost of water per month	341	57.2	(114)	277	58.1	(118)
Days of piped water per month (days/month)	163	7.88	(4.93)	130	8.45	(5.07)
Hours of water in normal week (hours/week)	163	42.8	(33.6)	130	46.7	(33.9)
Wastewater characteristics						
Business has a wastewater management system	341	0.69	(0.46)	278	0.68	(0.47)
Wastewater is connected to sewer	234	0.93	(0.25)	190	0.92	(0.28)
Monthly cost of sending wastewater to sewer	218	7.22	(13.2)	174	6.21	(11.0)
Monthly cost of sending wastewater to septic tank / field	14	13.1	(20.0)	14	13.1	(20.0)

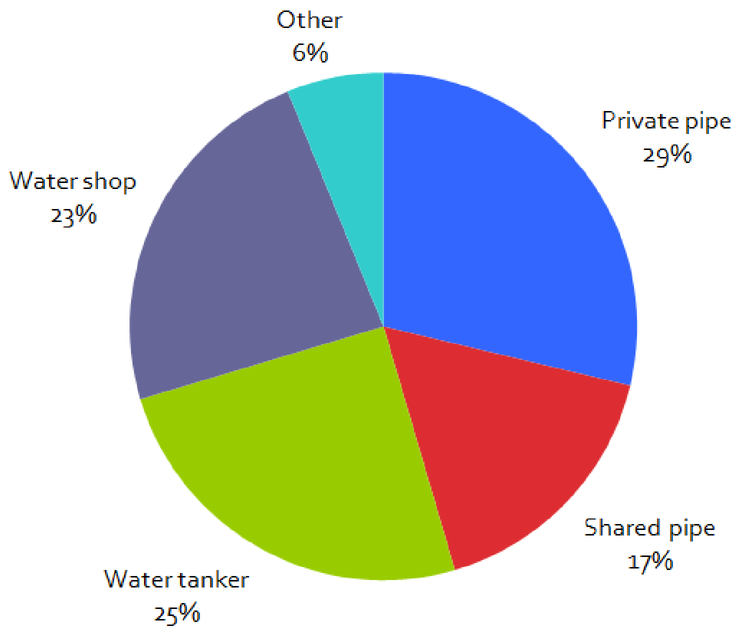


Figure C1. Distribution of main water sources used by surveyed enterprises (n=341)

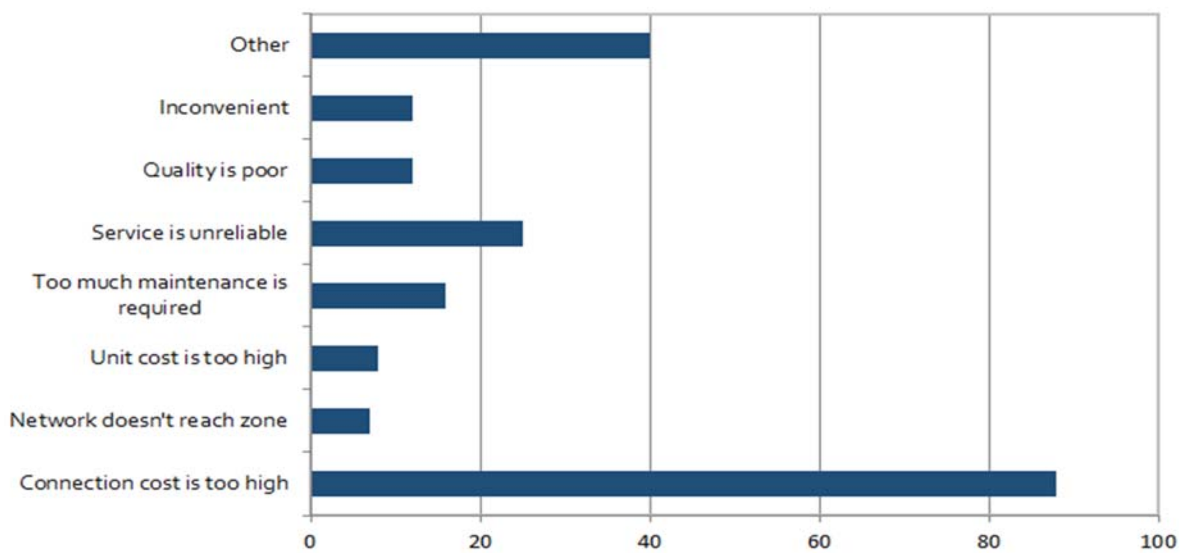


Figure C2. Reasons why enterprises do not have piped water (n=178)

Appendix D: Calculation of coping costs

Table D1. Definitions of water- and wastewater related coping cost variables

Coping Cost Category	Data Source	Assumptions	Formula
Non-network water expenditures	• Monthly non-network water purchases (p_i) for all non-network sources (i)	None	$\sum_{i=1}^{7} p_i$
Water collection costs	• Estimates of water collection time (min/trip) (t_i) for non-network water sources (i) • Estimates of monthly quantities (m^3) (q_i) used of non-network water sources (i)	• One trip/week and four weeks/month • Value of time is average wage (w)	$\sum_{i=1}^{7}(t_i/60) * w * 4$
Water treatment costs	• Estimates of monthly treatment costs (c) • Estimates of equipment costs (e)	• 5 year lifespan of equipment • 5% discount rate	$c + \frac{e}{1.05^{5*12}}$
Water storage costs	• Estimates of monthly costs of cleaning storage containers (S)	NONE	S
Expenses on in-house water repairs	• Estimates of yearly repair costs (r) • Estimates of time spent on repairs (s)	• Value of time is average wage (w)	$\frac{r+s*w}{12}$
Toilet cleaning costs	• Estimates of monthly time costs of cleaning toilets (c)	None	c
Toilet infrastructure costs	• Estimates of costs to replace toilet (r) • Reported connection fees to WAJ-wastewater (w)	• Average lifespan of toilet is 20 years • 5% discount rate	$(0.08 * (r + w))/12$
Time spent on trips to toilet	• Estimates of time (minutes/trip) spent walking to toilet for households with shared toilets (t)	• Value of time = average wage (w) • 3 trips/day per household member. • Household size=h.	$\left(\frac{t}{60}\right) * w * 3h$
Pit emptying costs	• Cost of emptying pit (p) • Frequency of emptying pit in months (m)	None	$\frac{p}{12} * m$