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Can perceptions of reduction in physical water availability affect irrigation behaviour? Evidence from Jordan

by
Kashi Kafle
Soumya Balasubramanya

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Authors:
Kashi Kafle and Soumya Balasubramanya

ISBN 978-92-9266-119-9
Printed August 2021

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Acknowledgements

This publication was partly made possible by the support of the American people through the United States Agency for International Development (USAID), under the terms of Award No. AID-ME-IO-15-003. Additional support came from Mercy Corps Jordan, through their USAID-funded program “Water Innovations Technologies” (Cooperative Agreement #AID-278-A-17-00002, CFDA # 98.001 between USAID and Mercy Corps Jordan), and from the CGIAR Research Program on Water, Land and Ecosystems. The contents of this publication are the sole responsibility of the authors and do not necessarily reflect the views of the United States Agency for International Development, of the United States Government, or of Mercy Corps Jordan. We would like to thank David Stifel, Marie-Charlotte Buisson, and the participants of IWMI’s Economics Seminar Series for discussions, comments and suggestions. We also thank Aslihan Arslan (the research series editor), Dennis Wichelns (external reviewer) and two anonymous IFAD internal reviewers for constructive feedback on previous versions. All remaining errors belong to the authors.

About the authors

Kashi Kafle is an Economist at the International Water Management Institute (IWMI). Prior to IWMI, Kashi worked at the International Fund for Agricultural Development (IFAD) and the World Bank. Kashi has several years of experience in designing and implementing complex multi-topic household and agricultural surveys in developing countries. His research has been published in highly regarded international journals, including *American Journal of Agricultural Economics*, *World Development,* and *Food Policy*. Kashi holds a Ph.D. in agricultural and applied economics from the University of Illinois at Urbana-Champaign.

Soumya Balasubramanya is a Senior Researcher and leads the Economics Research Group at the International Water Management Institute (IWMI). She collaborates with universities, public and private sector to influence research, dialogue and practice on inclusive and sustainable growth. Her research has been published in journals in agricultural, environmental and development economics; and has been featured in international news outlets in print, television and radio format. Her work has been used by international development aid agencies to inform investments and programs; and by governments in low and middle countries to design policy. Soumya received a Ph.D. in Environmental Economics and Policy from Duke University.

This issue of IFAD RS is dedicated to our dear colleague and Advisory Board member Edward Heinemann, who has left us in a tragic way and is dearly missed.

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Abstract

Frequent droughts and rapidly depleting groundwater reserves have deepened the water scarcity crisis in Jordan. Even though most farms use 'water-saving' technologies, groundwater depletion continues at an alarming rate. We investigate how perceptions of physical water availability in the past are related to farmers' current irrigation behaviour – frequency of irrigation and methods used in determining irrigation need. Using primary data from a survey of 414 commercial farms in Mafraq and Azraq governorates, we find that respondents who perceived reduction in physical water availability and faced agricultural losses in the past irrigated more frequently and were more likely to use self-judgement in determining irrigation need. These relationships were more pronounced for smaller farms, farms with sandy soil, mono-cropping farms and farms where the owner was the manager. These effects were lower for farms that preferred internet-based and in-person approaches for receiving irrigation advice. In addition, while the frequency of irrigation was higher among stone-fruit farms, the probability of using self-judgement in determining irrigation need was higher in olive farms and vegetable farms. We argue that farmers' irrigation behaviour must be considered for groundwater management policy and planning in Jordan.

1. Introduction

In the face of climate change, the demand for irrigation has increased faster than ever before, putting serious pressure on the limited groundwater resources (Kreins et al., 2015; Taylor et al., 2013; Wada et al., 2010; Zaveri et al., 2016). Policymakers are dealing with a difficult task of reducing water resource depletion without jeopardizing agricultural production. Technologies such as drip irrigation systems have been promoted as a way to adapt to climate change and 'save' water by increasing irrigation efficiency, typically defined as greater value of output per cubic meter of water used (Hussein, 2018; Perry et al., 2017). Less attention has been paid to understanding the irrigation behaviour of farmers.

Existing evidence suggests that improving water application methods are neither necessary nor sufficient for reducing over-abstraction of groundwater, primarily because 'water-saving' technologies alone are not likely to incentivize reduction in water use (Grafton et al., 2018; Perry et al., 2017). Though improved irrigation efficiency might reduce water use at the field level, ceteris paribus, it almost always increases water consumption at the basin level as farmers typically make other adjustments (Koech and Langat, 2018; Perry, 2007). Multiple studies have shown that 'water-saving' irrigation technologies increase crop yield and reduce marginal cost of irrigation, incentivizing farmers to expand production through acreage expansion or switching to water-intensive crops, thus leading to more efficient water use along with greater use of water, and higher output (Ferchichi et al., 2017; Pfeiffer and Lin, 2014; Sears et al., 2018; Ward and Pulido-Velazquez, 2008). Paradoxically, drip irrigation is not likely to be very helpful for adapting to climate change over the longer term, as it increases water demand which eventually leads to over-abstraction of groundwater, referred to as Jevons' paradox (Frisvold and Bai, 2016; Perry, 2007; Sears et al., 2018).

Since 'water-saving' technologies alone are not effective in 'saving' water, researchers have called for a better understanding of other aspects of groundwater irrigation. Some have suggested combining 'water-saving' technologies with appropriate price incentives for farmers (Dahmus, 2014; Ramírez et al., 2011), while others have suggested stricter regulations on groundwater abstractions (Kemper, 2001; Schlager, 2007), and the use of water accounting for understanding groundwater needs against availability (Batchelor et al., 2016; Humphreys et al., 2010; Steduto et al., 2012). While improving agricultural water management by understanding farmers' irrigation behaviour can be an important aspect, it has not received much attention either in the literature or in irrigation policies (Grafton et al., 2018; Perry et al., 2017; Sears et al., 2018). Most irrigation policies and interventions primarily focus on supply side constraints, paying little attention to demand side features e.g. irrigation behaviour. Understanding irrigation behaviour can be an important demand side management strategy because these are likely to be influenced by the farmer's individual and socio-demographic characteristics (Frija et al., 2016); characteristics and irrigation practices of other farmers (e.g. Chabé-Ferret et al. 2019) ; social and cultural norms (e.g. Burton and Paragahawewa 2011; Rahimi-Feyzabad et al. 2020); and institutional trust (e.g. Jorgensen, Graymore, and O'Toole 2009). Notwithstanding these few studies, the literature has largely overlooked the importance of irrigation behaviour.

Understanding farmers' irrigation behaviour is especially important in a setting where farmers are aware of reductions in the physical availability of water and where the risk of water-related agricultural losses is high (Frija et al., 2016). Farmers can respond to these risks in a variety of ways e.g. using more irrigation efficient technologies such as drip irrigation or switching to less water-intensive crops. Farmers could reduce cultivated areas over the medium and long term, but this is likely to vary depending on whether the crop is an annual or a perennial (Alauddin and Sarker, 2014; Cho and McCarl, 2017; García-Vila et al., 2008). Paradoxically, they could also resort to applying more irrigation, especially if the marginal return to irrigation is higher than the marginal cost (e.g. see Frija et al., 2016). Applying more irrigation can be rational in this context, since farmers are guided by reducing risk of crop loss and increasing farm revenues, and not by 'saving' water (Lin et al., 2008; Mondaca-Duarte et al., 2020). As a consequence, farmers may apply irrigation more frequently than needed as a strategy to reduce the probability of crop loss (e.g. Ferchichi et al., 2017; Frija et al., 2016). Similarly, farmers may use self-judgement in determining irrigation needs, again to lower crop loss.

The Hashemite Kingdom of Jordan presents a unique case to investigate whether perceptions of reduced physical water availability in the past can alter current irrigation behaviour. Jordan is one of the most ‘water-scarce countries in the world’, and is experiencing increasingly intense and frequent droughts (IPCC, 2014; Perry et al., 2017). Groundwater is the country’s most important source of water for agriculture, and has been over-abstracted (Al Naber and Molle, 2017).

The highlands of Jordan are completely dependent on groundwater; there are no surface water sources and rainfall is negligible. Agriculture primarily consists of perennials, mostly olives and stone-fruits, plus some vegetables, cultivated in large farms, where most farms range between 30-50 hectares in size. The physical availability of groundwater is falling (Al-Qinna et al., 2011; Schyns et al., 2); geologists have estimated that, on average, groundwater level is falling by about one metre a year (Goode, 2012). As farmers have experienced an increase in abstraction costs due to this falling groundwater levels (Alqadi and Kumar, 2011), the state has responded by lowering (already subsidized) electricity tariffs; and increasing caps on the abstraction volume per well to a high volume of 150,000 m3 (Al Naber and Molle, 2017; Venot and Molle, 2008), in what some have described as a ‘relationship of patronage’ between the state and local leaders who have jurisdiction over land (Closas and Molle, 2016). Many wells are not metered, and when metered, can be faulty. Fees on groundwater kick in only when the volume of abstraction crosses the cap.

The cap is large enough for smaller farms not to exceed it and the groundwater fees are small enough that farms exceeding the cap would benefit from paying the fees rather than reducing water use (Venot and Molle, 2008). These concessions have encouraged an expansion of irrigated agriculture; between 2005 and 2011, cultivated (irrigated) area increased from 6,120 ha to 11,433 ha (Al Naber and Molle, 2017). Since highland farms have been using drip irrigation over for at least 15-20 years, the role of increasing irrigation efficiency as a strategy to address economic scarcity is limited. Another indicator of falling physical availability of water is that farmers have to deepen their wells periodically, or drill deeper ones as water levels fall (Al Naber and Molle, 2017; Closas and Molle, 2016). This often happens after farms have faced agricultural losses due to not being able to abstract ‘sufficient’ water for their operations. In this landscape of clearly falling physical availability of water and state-farmer patronage, it is unclear whether highland farmers are able to receive clear ‘signals’ of economic water scarcity through price signals (pumping costs, groundwater fees). These dynamics suggest that farmers are likely to perceive water scarcity physically rather than economically.

This paper investigates whether farmers’ perceptions of physical water availability in the past affect current irrigation behaviour (measured by the frequency of irrigation and methods used in determining irrigation need). Farmers’ perceptions of reduction in physical water availability were elicited by asking them the number of years in the past 10 years the farm experienced a reduction in water availability that was detrimental to cultivation. In a setting where meteorological droughts are common, farms don’t face signals of economic scarcity, metering is weakly enforced and farms have privately adapted to these circumstances, eliciting perceptions of water availability by relating them to agricultural loss is perhaps justified. Primary data from a survey of over 400 commercial fruit farms in Azraq and Mafraq governorates are used to examine this question. Farms typically cultivate olives, grapes and other fruit trees including pomegranate, citrus, peaches and plums. Average farm sizes are around 300 dunum (30 hectares), with smaller farms averaging around 9 hectares (from the study sample).

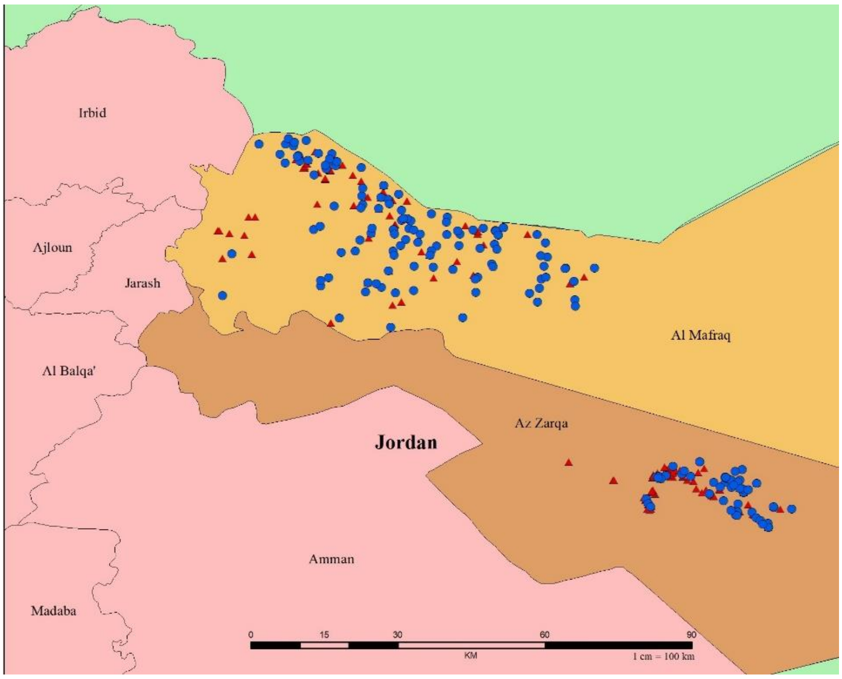
This analysis makes two important contributions to the literature. First, it provides evidence of a positive relationship between perceptions of physical water availability in the past and current irrigation behaviour among commercial farmers who have been using drip irrigation for extended periods of time. Second, the analysis shows that the relationship between farmers’ perceptions of reduction in physical water availability in the past and current irrigation behaviour differ by farm characteristics, cropping pattern, land-holding size and farm management practices. The evidence of a heterogeneous relationship between the perceptions of physical water availability in the past and current irrigation behaviour is crucial for designing targeted policy interventions.

The paper proceeds as follows. In section 2 the study design, questionnaire and data are defined. Section 3 presents conceptual framework and econometric method. Descriptive and econometric results are presented in section 4. Section 5 concludes.

2. Survey design and Data

The data come from a cross-sectional survey of 414 farms implemented in Azraq (also known as Az Zarqa) and Mafraq governorates in June 2019. In Azraq, 210 farms were randomly selected for interviews and in Mafraq, 204 farms. The sample size was determined using power calculations to assure 80% statistical power and 5% type I error. Figure 1 shows the location of farms in Azraq and Mafraq governorates. Locations denoted with blue circles are larger farms (≥ 20 ha) and locations denoted with red triangles are smaller farms (<20 ha).

Figure 1. Location of farms surveyed in Al Mafraq and Az Zarqa, Jordan.



[Notes: Locations denoted with blue circle are large farms (≥ 20 ha) and locations denoted with red triangle are small farms (<20 ha)]

A list of commercial fruit farms in Azraq and Mafraq was obtained from Mercy Corps Jordan and the International Centre for Biosaline Agriculture, who have been working in the region for the past 10-15 years to improve on-farm water application. Sample farms were selected randomly from the full list of farms using probability-proportional-to-size (PPS) sampling. The study sample is representative of all farms in these two governorates.

A survey questionnaire was designed after conducting detailed key informant interviews and focus group discussions with farmer groups in Azraq and Mafraq. Data was collected on the characteristics of farms, farm owners and farm managers; farm management practices; division of irrigation-related tasks on the farm; on-farm water management practices; farmer beliefs about groundwater uses and management; irrigation practices; and perception of reduction in physical water availability and its impacts on agricultural losses. In all interviews, the manager of the farm (either the owner-manager – the owner who was also the manager – or the hired manager) was interviewed.

Perception of reduction in physical water availability and related losses

In the survey, farmers were asked “whether they had perceived reduction in physical water availability on their farm that had detrimentally affected agricultural activities in the past 10 years”. Responses were recorded as the count of years between 0 and 10 where respondents perceived such a reduction in water availability. For easy interpretation, responses were converted to a binary indicator; farmers who perceived reduction in physical water availability for at least one of the past 10 years are assigned a value of 1. Respondents who reported reduction in physical water availability for at least one of the past 10 years were asked to identify whether they had experienced any agricultural losses due to reduction in water availability.

Irrigation behaviour

Farmers were asked how often they irrigated their crops or trees. Respondents were provided with multiple irrigation frequencies and asked to choose from the following options:

1) daily

2) a few times a week

3) weekly

4) a few times a month

5) monthly

6) bi-monthly

7) once a year

8) never.

This information was elicited at farm level because most farms specialized in (one of) fruit trees, olives or vegetables and respondents were asked to think about the crop with the largest cultivated area when answering. As the schedule of irrigation varies by crop types, soil types, irrigation methods and climate, irrigation frequencies were converted into an indicator for easy interpretation. Specifically, the irrigation frequency data elicited in the survey was compared with the FAO recommended crop- and soil-specific irrigation schedule for hot and dry climates (Brouwer et al., 1989). The FAO irrigation schedule presented in Table 1 is also the recommended schedule in Jordan by the Ministry of Water and Irrigation. In this framework, applying irrigation more often than the recommended schedule was considered more-frequent irrigation.

Table 1. Irrigation frequency threshold by crop and soil types for dry and hot climate for drip irrigators.

Crop type	**Soil type**		
	Sandy soil	**Loamy soil**	**Clay soil**
fruit trees (e.g. pomegranate, plum, peach)	Daily	Few times a week	Few times a week
olives, grapes	Few times a week	Few times a week	Weekly
vegetables	Daily	Daily	Daily

Source: FAO crop irrigation requirement data (Brouwer, Prins, and Heibloem, 1989).

Farmers were also asked what determined the timing of irrigation for their crops or trees. Respondents were provided four options: 1) ‘follow crop’s calendar’ 2) ‘use moisture probe’ 3) ‘visually examine the soil’ 4) ‘irrigate when feel the need’ and they could choose as many options as applicable to their farm. Responses were used to create a binary indicator for irrigation behaviour – self-determined irrigation, where the third and fourth response were coded as one, and the first two as zero. In cases where farmers selected multiple options, responses were made mutually exclusive in this order: follow crop’s calendar, use moisture probe, visually examine the soil, and irrigate when the irrigation need was felt. Use of crop calendar and moisture probe in determining irrigation need were always preferred over the use of subjective methods. Hence, a farmer who irrigated one crop following crop calendar but irrigated another crop when they felt the need would get assigned a zero for self-determined irrigation.

3. Methodology

Let *i* indicate a farmer and *j* indicate the farmer's irrigation behaviour – 1) more-frequent irrigation 2) self-determined irrigation, hence *j = 1, 2*. Let y_{ij} indicate farmer *i*'s irrigation behaviour *j*, w_i be a dummy variable that indicates if farmer *i* perceived a reduction in physical water-availability, l_i indicate agricultural loss experienced by farmer *i* who reported reductions in physical water availability, and X be a vector of farm and farmer characteristics.

$$y_{i1} = \alpha_{i1} + \beta_{i1} w_i + \theta_{i1} l_i + \Pi_{i1} X_i + \varepsilon_{i1} \quad (1)$$

$$y_{i2} = \alpha_{i2} + \beta_{i2} w_i + \theta_{i2} l_i + \Pi_{i2} X_i + \varepsilon_{i2} \quad (2)$$

Equations 1 and 2 form a system of equations as both equations are characterized by the same set of variables, and both outcome variables are co-determined.

Since the outcome variables in equations 1 and 2 (y_{ij}) are co-determined, ordinary least squares (OLS) estimator yields inconsistent estimates. Therefore, the seemingly unrelated regression (SUR) estimator is used to estimate the effects of the perception of physical water availability on irrigation behaviours. For completeness, equations 1 and 2 are estimated separately with OLS estimator as well, but our preferred estimator is SUR. The coefficient of interest is β_{ij} representing the effect of the perception of reduction on physical water availability of farmer *i* on irrigation behaviour *j*. We are also interested on the coefficient estimate θ_{ij}, which is the effect of agricultural losses (experienced by farmers who perceived reductions in physical water availability) on irrigation behaviour *j*. Assuming that strict exogeneity holds, i.e. $E(\varepsilon_{ij} | w_i, l_i, X_i) = 0, \forall j = 1, 2$ the coefficients β_{ij} and θ_{ij} are identified.

However, one can argue that the perception of reduction in physical water availability (w_i) and irrigation behaviour may be influenced by factors that are unobservable, implying that the error term ε_{ij} is likely directly correlated with the outcome variables. We address the potential endogeneity concern by using the instrumental variable (IV) approach. IV approach and results are discussed in section 4.3 under robustness checks.

4. Results and discussion

Descriptive results

Table 2 presents summary statistics for the perception of reduction in physical water availability and its outcomes. About 59% of the sample farms reported that they perceived reductions in physical water availability for at least one year in the past 10. On average, these farms perceived such reductions between two and three years in the past 10 years. Among the farms that perceived reductions in physical water availability, about 85% of them reported loss of agricultural production; 57% farms lost income, 50% farms lost trees/crops, and 25% lost farm assets. Only 4% of farms that perceived reductions in physical water availability did not report any agricultural loss.

Table 2. Perceptions of physical water availability and its outcomes.

Variables *(Percentage of farms, unless otherwise indicated)*	**Mean**	**SD**
	1	*2*
Perceived reduction in physical water availability	59.18	49.21
Number of years perceived redn. in physical water availability (count)	2.62	3.05
Number of farms	**414**	
Outcome		
Loss of agricultural production	84.89	35.88
Loss of income	57.55	49.53
Loss of trees/crops	49.79	50.10
Loss of farm assets	25.31	43.56
Migration of family members	1.21	10.98
Nothing happened	3.67	18.85
Number of farms	**245**	

Notes: Point estimates in the first column are means. Standard deviations are in the second column.

Table 3 presents farm characteristics and cultivation practices. The first panel presents a summary of farm characteristics including farm size, topography and the number of wells. The average farm size was 35 hectare (ha)[1]. Farms that perceived reduction in physical water availability at least once were slightly larger (37 ha) than other farms (32 ha), but the difference was not statistically significant. Since most farms were large commercial fruit farms, hiring an outside manager was not uncommon.

In about 57% of the farms, the owner was also the primary farm manager – these farms are called owner-manager farms. Perception of reduction in physical water availability was less common among owner-manager farms. Fifty-one percent of the farms that perceived reductions in physical water availability were managed by the owner-manager but the share was more than 65% for the farms that did not perceive reduction in physical water availability. The majority of the farms had been operating under the current ownership for at least 15 years. On average, more than 86% of farms had one or more metered wells. Metered wells were more common among farms whose managers perceived reductions in physical water availability (90%) than farms whose managers did not perceive reductions in physical water availability (82%), likely indicating a common presence of non-metered (hence illegal) wells on the latter types of farms.[2]

[1] Area was converted from *dunum* to hectare. 1 hectare = 10 *dunums*.

[2] Illegal wells are very common in the highlands in Jordan, where this study is based. As it is socially and politically sensitive, we were unable to ask respondents questions about illegal wells on the farm. It is unlikely that a farm would only have illegal wells and no legal wells.

Table 3. Farm characteristics and cultivation practices.

Farm characteristics *(Percentage of farms, unless otherwise indicated)*	**All farms**	**Farms perceiving redn. in physical water availability**	**Other farms**	**P-value (2-3)**
	1	***2***	***3***	***4***
Farm area (Ha)	35.27	37.52	32.01	0.23
	(2.37)	(3.43)	(2.99)	
Slope	39.37	42.04	35.50	0.17
	(2.26)	(2.82)	(3.65)	
Owner is the manager of the farm	56.76	51.02	65.09	0.00***
	(2.43)	(2.20)	(3.69)	
Number of years under current owner	16.63	17.45	15.43	0.09*
	(0.58)	(0.73)	(0.92)	
Farm has one or more metered wells	86.47	89.80	81.66	0.02**
	(1.64)	(1.92)	(2.88)	
Number of metered wells on the farm (count)	1.18	1.17	1.18	0.90
	(0.03)	(0.04)	(0.05)	
Cultivation practices				
Farm is cultivated by the owner/employees	89.61	87.35	92.90	0.06*
	(1.49)	(2.11)	(1.99)	
Farm is rented out or contract farming	10.39	12.65	7.10	0.06*
	(1.49)	(2.11)	(1.99)	
Types of farm ownership				
Private owner, single	55.07	55.10	55.03	0.99
	(2.40)	(3.13)	(3.75)	
Private owner, multiple	39.86	40.00	39.64	0.94
	(2.40)	(3.12)	(3.76)	
Government or other owner	5.07	4.90	5.33	0.85
	(1.06)	(1.36)	(1.70)	
Number of farms	**414**	**245**	**169**	

Notes: Point estimates are percentages unless otherwise indicated. Standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels respectively.

The second panel in Table 3 presents statistics for key cultivation practices. About 90% of the farms were cultivated by the owners/employees and the remaining 10% of farms were rented out. More than 95% of the farms were privately owned – 55% by single owners and 40% by multiple owners. The remaining 5% farms were owned by either co-operatives or by the government. There was no difference in perception of reduction in physical water availability by farm ownership.

Table 4 presents the farm owners' and managers' characteristics including gender, age, education, location of residence, and primary job status. Overall, characteristics of the farm owners and managers were more or less similar between farms whose managers perceived a reduction in physical water availability and other farms. The average age of farm owners was 56 years. More than 98% of the owners were male and about half of them had completed high school or higher grades. Though only about 14% of the owners resided on or near the farm, more than 50% of the owners' primary job was to manage their farm. The managers were slightly younger than the owners, most were male and about 40% of the managers had completed high school. More than one-third of managers resided on the farm and about 42% of the managers' primary job was something else other than managing this farm.

Table 4. Farm owners' and managers' characteristics.

Characteristics *(percentage of farms, unless otherwise indicated)*	**All farms**	**Farms perceiving redn. in physical water availability**	**other farms**	**P-value (2-3)**
Farm owners	***1***	***2***	***3***	***4***
Age (years)	55.98	56.44	55.31	0.44
	(0.71)	(0.91)	(1.15)	
Gender: Male	98.79	98.77	98.82	0.97
	(0.53)	(0.69)	(0.83)	
Education: Completed high school	48.07	50.20	44.97	0.29
	(2.46)	(3.18)	(3.85)	
Resides on the farm	14.25	13.06	15.98	0.41
	(1.72)	(2.14)	(2.83)	
Primary job is to manage this farm	50.97	48.57	54.44	0.24
	(2.41)	(3.06)	(3.83)	
Number of farms				
Farm managers				
Age (years)	48.13	47.54	48.98	0.30
	(0.67)	(0.85)	(1.08)	
Gender: Male	100	100	100	-
	-	-	-	
Education: Completed high school	39.37	42.86	34.32	0.08*
	(2.40)	(3.17)	(3.66)	
Resides on the farm	34.30	37.55	29.59	0.09*
	(2.33)	(3.10)	(3.53)	
Primary job is to manage this farm	57.73	59.18	55.62	0.47
	(2.41)	(3.09)	(3.83)	
Number of farms	**414**	**245**	**169**	

Notes: Point estimates are percentages unless otherwise indicated. Standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively.

Figure 2 presents summary statistics on types of irrigation methods used by perception of reduction in physical water availability. More than 90% of the farms were using high-tech irrigation methods – drip and sprinkler irrigation. There was no apparent difference in the share of drip irrigators by perception of reduction in physical water availability. While about 3% of farms used sprinkler irrigation, none of the farms that perceived reductions in physical water availability reported using sprinklers. Other methods of irrigation, which included surface run-off, open-tube irrigation and furrow irrigation, were also reported by a small number of both types of farms.

Figure 2. Irrigation methods in use, by perception of reduction in physical water availability.

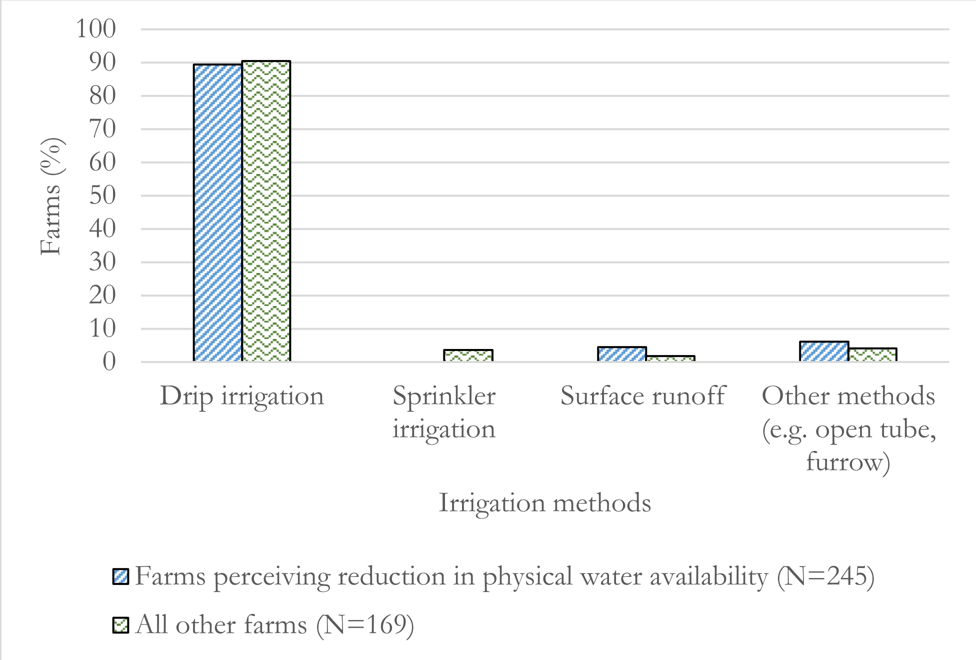


Table 5 presents summary statistics on irrigation behaviour. The first panel presents statistics on different categories of irrigation frequency reported in the survey. About 20% of the farms irrigated daily, 50% irrigated a few times a week and about 22% irrigated weekly. The remaining 8% farms irrigated a few times a month or less frequently. Results indicate that farms whose managers perceived a reduction on physical water availability irrigated more frequently than other farms. Specifically, daily irrigation was 11% higher for farms that perceived reduction in physical water availability (25%) than for farms that didn't perceive similarly (14%). Less frequent irrigation intervals such as 'few times a week' and 'weekly irrigation' were more common for farms whose managers did not perceive reductions in physical water availability.

Table 5. Irrigation frequency and methods used in determining irrigation need.

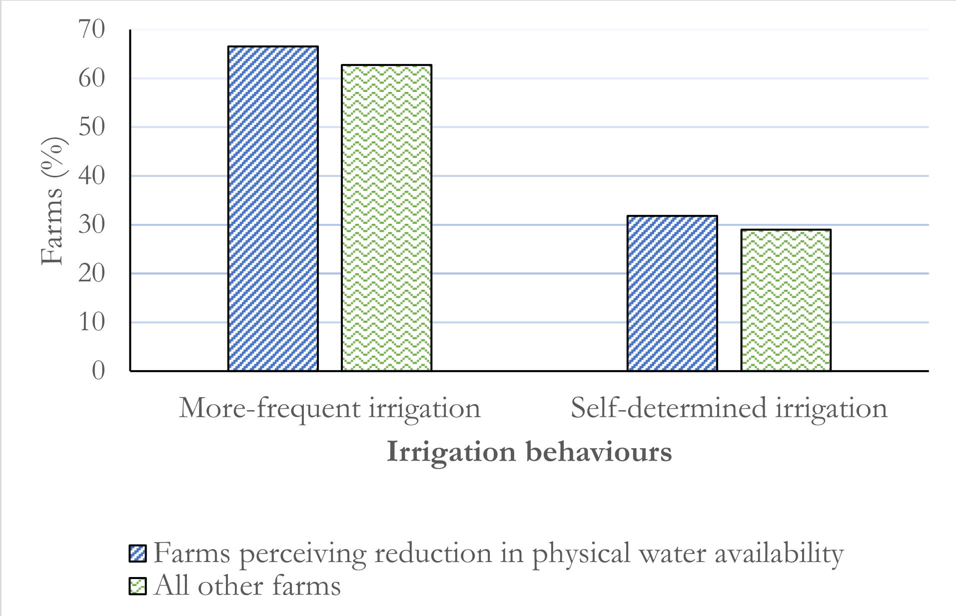
	All farms	**Farms perceiving red. in physical water availability**	**All other farms**	**P-value (2-3)**
	1	***2***	***3***	***4***
Irrigation Frequency				
Daily	20.3	24.5	14.2	0.01***
	(1.9)	(2.7)	(2.6)	
Few times a week	50.0	46.5	55.0	0.09*
	(2.4)	(3.1)	(3.8)	
Weekly	21.7	19.6	24.9	0.21
	(1.9)	(2.3)	(3.2)	
Few times a month or less	8.0	9.4	5.9	0.18
frequently	(1.3)	(1.9)	(1.8)	
Determining irrigation need				
Examine the soil moisture	24.4	22.4	27.2	0.27
	(2.1)	(2.7)	(3.4)	
Follow crop's irrigation calendar	66.9	65.3	69.2	0.40
	(2.3)	(3.0)	(3.6)	
Irrigate when we feel the need	28.0	29.0	26.6	0.60
	(2.2)	(2.9)	(3.4)	
Use moisture probes	2.2	2.0	2.4	0.82
	(0.7)	(0.9)	(1.2)	
Number of farms	**414**	**245**	**169**	

Notes: Point estimates are proportions. Standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively.

The second panel in Table 5 presents farmers' self-reported methods used in determining irrigation need. Respondents were allowed to choose as many options as applicable to their farm. On average, about 70% of the farms used 'standard' methods in determining irrigation need; 67% of the farms followed crop-specific irrigation calendar and more than 2% of the farms used moisture probe. However, the use of these methods was not exclusive. More than 50% of the farms reported determining irrigation need by using self-judgement; 24% examined soil moisture manually and 28% applied irrigation when they felt the need.

Irrigation behaviours presented in Table 5 form the basis for key variables of interest for the analysis – more frequent irrigation and self-determined irrigation (defined in section 2.2). Figure 3 presents the prevalence of these behaviours. About 65% of the farms irrigated more frequently than the recommended schedule and about 30% of the farms used self-judgement in determining irrigation need. Both of these irrigation behaviours – more-frequent irrigation and self-determined irrigation – were more common among farms that perceived reductions in physical water availability than farms that did not, but the differences were not statistically significant.

Figure 3. Relationship between perception of reduction in physical water availability and irrigation behaviour.



Econometric results

Table 6 presents the OLS and SUR results for the effects of perceptions in reduction of physical water availability on irrigation behaviour. OLS results are presented for completeness. We describe the results from our preferred estimator (i.e. SUR) only, because the OLS results are inconsistent. As reported in Table 6, the coefficient estimates from OLS results have greater standard errors than that of SUR results. The SUR results in Table 6 show that respondents, who perceived reductions in physical water availability for at least one year in the past 10 years, increased more frequent irrigation by 3.6% ($p = 0.69$) and self-determined irrigation by 19% ($p < 0.03$). Effects of experiencing agricultural losses conditional on perceiving reduction in physical water availability were also explored. Since these losses could only be observed for those who perceived a reduction in physical water availability, coefficient estimates on the 'loss variables' should not be interpreted in isolation. Instead, coefficient estimate on each 'loss variable' should be interpreted jointly with the coefficient estimate on perception of reduction in physical water availability. As such, experiencing agricultural losses from reductions in physical water availability increased self-determined irrigation by 18% but reduced more-frequent irrigation by about 11%.

Table 6. Effects of perception of reduction in physical water availability and associated loss on irrigation behaviour.

	More-frequent irrigation		**Self-determined irrigation**	
	OLS	***SUR***	***OLS***	***SUR***
Perception of reduction in physical water availability	0.036	0.034	0.19**	0.19**
	(0.099)	(0.091)	(0.095)	(0.089)
Agricultural loss due to reduction in physical water availability				
Loss of farm income	-0.13**	-0.14**	-0.015	-0.010
	(0.065)	(0.066)	(0.068)	(0.065)
Loss of assets	-0.012	-0.0070	0.036	0.033
	(0.079)	(0.076)	(0.074)	(0.074)
Loss of agricultural production	0.11	0.11	-0.16*	-0.16*
	(0.092)	(0.085)	(0.089)	(0.083)
Loss of trees	0.013	0.018	-0.062	-0.066
	(0.066)	(0.065)	(0.065)	(0.063)
Irrigation				
Drip irrigation	0.22	0.21*	0.053	0.056
	(0.14)	(0.13)	(0.14)	(0.12)
Sprinkler irrigation	0.39**	0.39*	0.17	0.17
	(0.18)	(0.23)	(0.27)	(0.23)
Ever met irrigation expert in	0.12**	0.12**	0.00001	0.0020
the past 5 years	(0.048)	(0.046)	(0.047)	(0.045)
Additional controls	Yes	Yes	Yes	Yes
Constant	0.16	0.16	0.32	0.32
	(0.22)	(0.22)	(0.22)	(0.22)
Number of farms	**414**	**414**	**414**	**414**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively.

Additional control covariates include farm manager's characteristics (owner-manager, age, education level, primary job, and residence), farm characteristics (farm size, slope, type of ownership) and farm management practices (registered wells, cultivation status, manager is in-charge for irrigation, number of salaried and family workers, and frequency of meeting between workers and managers).

The second panel in Table 6 reports coefficient estimates on different irrigation variables. These variables were included in the model as control covariates along with farm details, farm manager's characteristics and farm management practices. Current irrigation method was elicited with three different types: drip irrigation, sprinkler irrigation and other irrigation method, which included surface run-off, furrow irrigation, and open-tube irrigation. More than 90% of the farms in our data reported using drip irrigation. Compared to farmers, who used other irrigation methods, farmers using high-tech irrigation (drip or sprinkler) were more likely to apply irrigation more frequently or use self-judgement in determining irrigation need.

Consultation with irrigation experts was positively correlated with irrigation behaviour; farmers, who met irrigation experts, were 12% more likely to irrigate more frequently or use self-judgement in determining irrigation need ($p < 0.01$). This is not surprising; typically, farmers seek support during or after the crisis occurs, not before. Farmers who perceived reductions in physical water availability, and hence were more likely to irrigate more frequently or use self-judgement, might have consulted with irrigation experts more often than the farmers, who did not perceive reductions in physical water availability.

Results by crop types

Table 7 presents SUR results on the effects of perception of reduction in physical water availability on irrigation behaviour by crop types. This is explored to understand the potential differences in irrigation behaviour of different types of farmers. For convenience of presentation, coefficient estimates for control variables are not displayed in Table 7 (but were included in the regressions).[3]

[3] In each case, control covariates include i) agricultural loss conditional on perceiving reduction in physical water availability (loss of income, loss of farm assets, loss of trees/crops, loss of agricultural production, and loss of nothing), ii) irrigation (drip irrigation, sprinkle irrigation, and use of irrigation extension services), iii) farm manager's characteristics (owner-manager, age, education level, primary job, and residence), iv) farm characteristics (farm size, slope, type of ownership), farm management practices (registered wells, cultivation status, manager is in-charge for irrigation, number of salaried and family workers, and frequency of meeting between workers and managers).

Table 7. Heterogeneous effects of perception of reduction in physical water availability on irrigation behaviour, by crop types.

	Irrigation behaviour	
	More-frequent irrigation	**Self-determined irrigation**
Olive farms	*1*	*2*
Perception of reduction in physical water availability	-0.056	0.26**
	(0.12)	(0.12)
Controls	Yes	Yes
Number of farms	**230**	**230**
Fruit farms		
Perception of reduction in physical water availability	0.17	0.092
	(0.16)	(0.15)
Controls	Yes	Yes
Number of farms	**132**	**132**
Vegetable farms		
Perception of reduction in physical water availability	0.24	0.76***
	(0.21)	(0.27)
Controls	Yes	Yes
Number of farms	**46**	**46**
Mono-croppers		
Perception of reduction in physical water availability	0.11	0.30**
	(0.13)	(0.13)
Controls	Yes	Yes
Number of farms	**189**	**189**
Multi-croppers		
Perception of reduction in physical water availability	0.069	0.16
	(0.12)	(0.12)
Controls	Yes	Yes
Number of farms	**225**	**225**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels respectively.

Results in Table 7 show that perception of reduction in physical water availability in the past was more likely to increase irrigation frequency and self-determined irrigation among olive farmers and vegetable farmers than among fruit farmers. Specifically, olive farmers and vegetable famers, who perceived a reduction in physical water availability, were more likely to employ self-determined irrigation by 26% ($p < 0.05$) and by 76% ($p < 0.01$) respectively. Perception of reduced water availability was positively correlated with more-frequent irrigation and self-determined irrigation among fruit farmers but these relationships were not statistically significant. When farms were categorized into two different groups by cropping pattern (mono-croppers and multi-croppers), mono-croppers that perceived a reduction in physical water availability were more likely to irrigate more frequently (11%, $p<0.24$) and also more likely to use self-judgement in determining irrigation need (30%, $p<0.05$) than their counterpart multi-croppers.

Results show that the relationship between perception of reduction in physical water availability in the past and irrigation behaviour was more pronounced for olive farmers and vegetable farmers than for fruit farmers. In addition, the relationship was amplified for mono-cropping farmers compared to multi-cropping farmers. These findings indicate that farmers' response to water stress differs not only by the type of crops they grow but also by the differences in cropping system.

Results by farm characteristics

Table 8 breaks down the effects of perception of reduction in physical water availability on irrigation behaviour by farm characteristics. Equation 2 was estimated with the SUR estimator for different farm typologies: large farms (20 ha or more), small farms (<20 ha), farms with sandy soil, farms managed by the owner-manager, farms managed by a hired manager, and farms that prefer in-person or internet-based approaches for receiving irrigation advice. Coefficient estimates are presented for perception of reduction in physical water availability only.[4]

Results show that the perception of reduction in physical water availability was positively associated with higher irrigation frequency and the use of self-judgement in determining irrigation need, primarily among smaller farms, farms with sandy soil, and farms where the owner was the manager. Specifically, for small farms (<20 ha), the probability of more-frequent irrigation was higher by 8% ($p<0.54$) and self-determined irrigation was higher by 33% ($p <0.01$). Perceiving of reduction in physical water availability was associated with a 23% increase in self-determined irrigation ($p<0.05$) for farms with sandy soil, and a 25% increase ($p <0.05$) for farms where the owner was the manager. In farms managed by a hired manager, a perception of reduction in physical water availability was associated with a 17% increase in self-determined irrigation, though the relationship was not statistically significant.

Results in the lowest panel show the relationship between the perceptions of a reduction in physical water availability and preferred channels for receiving irrigation advice. Farms that preferred in-person or internet-based approaches for receiving irrigation advice were less likely to irrigate more frequently or use self-judgement in determining irrigation needs. This indicates that irrigation extension programme may have a role to play in changing perceptions and irrigation behaviour.

[4] In each case, control covariates include i) Agricultural loss conditional on perceiving reduction in physical water availability (loss of farm income, loss of farm assets, loss of trees/crops, loss of agricultural production, and loss of nothing), ii) irrigation (drip irrigation, sprinkle irrigation, and use of irrigation extension services), iii) farm manager's characteristics (owner-manager, age, education level, primary job, and residence), iv) farm characteristics (farm size, slope, type of ownership), and v) farm management practices (registered wells, cultivation status, manager is in-charge for irrigation, number of salaried and family workers, and frequency of meeting between workers and managers).

Table 8. Heterogeneous effects of perception of reduction in physical water availability on irrigation behaviour, by farm characteristics.

	Irrigation behaviour	
	More-frequent irrigation	Self-determined irrigation
Large farms (>=20 Ha)	*1*	*2*
Perception of reduction in physical water availability	0.053	0.080
	(0.13)	(0.12)
Controls	Yes	Yes
Number of farms	**215**	**215**
Smaller farms (<20 Ha)		
Perception of reduction in physical water availability	0.081	0.33***
	(0.13)	(0.13)
Controls	Yes	Yes
Number of farms	**199**	**199**
Farms with sandy soil		
Perception of reduction in physical water availability	0.038	0.23**
	(0.11)	(0.11)
Controls	Yes	Yes
Number of farms	**249**	**249**
Owner manager		
Perception of redn. in physical water availability	0.13	0.25**
	(0.12)	(0.12)
Controls	Yes	Yes
Number of farms	**235**	**235**
Hired manager		
Perception of redn. in physical water availability	-0.16	0.17
	(0.14)	(0.14)
Controls	Yes	Yes
Number of farms	**272**	**272**
Preferred media for irrigation advice is in-person or internet-based approach		
Perception of reduction in physical water availability	-0.17	0.065
	(0.12)	(0.12)
Controls	Yes	Yes
Number of farms	**249**	**249**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels respectively.

Robustness checks

Multiple robustness checks were performed to confirm the relationship between the perception of reduction in physical water availability and irrigation behaviours. First, an instrumental variables approach was used, and second, placebo and falsification tests were employed.

Instrumental variables

The perception of a reduction in physical water availability was calculated by using farmers' beliefs about four different scenarios of groundwater use and management that were elicited during the survey. Respondents were presented with the following four statements:

1) *droughts have affected the groundwater level in the last five years*
2) *groundwater levels will rapidly fall in the next five years*
3) *groundwater level will be affected by farming activities in the next five years*
4) *my farm income will decrease in the next five years due to groundwater issues*.

Farmers' responses to these statements were recorded on a scale between 0 and 10. A response of zero meant the respondent completely disbelieved the statement, and a response of 10 meant the respondent completely believed it. For convenience in interpretation, responses were converted into a binary variable; responses between 0 and 5 were assigned 0 and those between 6 and 10 were assigned 1. Appendix Table A1 presents summary statistics for each of these belief variables.

Farmers' beliefs about these four different scenarios of groundwater use and management are likely valid instruments for perceptions of reduction in physical water availability, because farmers' beliefs about past or future groundwater levels do not directly affect their current irrigation behaviour. Any effects these four beliefs may have on irrigation behaviour will likely operate through the perception of reduction in physical water availability. This claim was assessed by regressing the outcome variables (irrigation behaviour) and the (likely) endogenous variable (perception of reduction in physical water availability) on each of the instrumental variables separately. Results are presented in appendix Table A2, demonstrating that while the perception of reduction in physical water availability was significantly correlated with the instrumental variables, the outcome variables were not correlated, suggesting that the four belief variables are orthogonal to irrigation behaviour, and likely valid instrumental variables.

Equation 2 was estimated with three stage least squares (3SLS) using the four belief variables as instruments for the perception of reduction in physical water availability. Table 9 presents the 3SLS results.[5] Overall, the 3SLS results are consistent with the SUR results in Table 6, in that farmers perceiving a reduction in physical water availability were more likely to irrigate more frequently and use self-judgement in determining irrigation need. Specifically, respondents who perceived a reduction in physical water availability were 26% more likely to irrigate more frequently ($p = 0.36$), and 32% more likely to use self-determined irrigation ($p = 0.70$), though these relationships were not statistically significant at 10% significance level. Coefficient estimates on agricultural losses conditional on perceiving a reduction in physical water availability are interpreted together with the coefficients on the perception of reduction in physical water availability. Results in Table 9 show that loss of farm income due to reduction in physical water availability was associated with 17% increase in more frequent irrigation ($p<0.05$). Likewise, loss of assets, loss of agricultural production and loss of trees/crops also affected irrigation behaviour in similar ways.

[5] Additional control covariates include farm manager's characteristics (owner-manager, age, education level, primary job and residence), farm characteristics (farm size, slope, type of ownership) and farm management practices (registered wells, cultivation status, manager is in charge of irrigation, number of salaried and family workers and frequency of meeting between workers and managers).

Table 9. Effects of perception of reduction in physical water availability on irrigation behaviour (3SLS results).

	Irrigation behaviour	
	More frequent irrigation	Self-determined irrigation
	1	*2*
Perception of reduction in physical water availability	0.26	0.32
	(0.39)	(0.38)
Agri. loss due to reduction in physical water availability		
Loss of farm income	-0.17**	-0.028
	(0.086)	(0.084)
Loss of assets	0.0046	0.040
	(0.079)	(0.077)
Loss of agricultural production	-0.040	-0.24
	(0.27)	(0.26)
Loss of trees	-0.021	-0.088
	(0.094)	(0.091)
Irrigation		
Drip irrigation	0.20	0.048
	(0.13)	(0.13)
Sprinkler irrigation	0.42*	0.18
	(0.24)	(0.23)
Ever met irrigation expert	0.13***	0.0058
in the past five years	(0.048)	(0.047)
Controls	Yes	Yes
Constant	0.12	0.30
	(0.24)	(0.23)
Number of farms	**414**	**414**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively.

Placebo tests

Placebo regressions were also conducted to estimate the effects of a randomly generated 'false' perception of reduction in physical water availability on irrigation behaviour. The 'false' variable was generated by using uniform distribution with a pre-determined sample mean of 0.59, the sample mean of the observed variable. Placebo regressions were run by using the SUR estimator with irrigation behaviour as outcome variables and the 'false' perception physical water availability as the key variable of interest. Results are presented in appendix Table A3. Results show that the 'false' perception variable had no statistically significant effects on irrigation behaviour, supporting the existence of a relationship between the perception of a reduction in physical water availability and current irrigation behaviour.

Falsification tests

Falsification tests were conducted to assess whether the perception of reduction in physical water availability affected outcome variables that it should not affect. Three different 'false' outcome variables were chosen – land-holding size, binary indicator for access to loan, and binary indicator for whether the manager was responsible for repair and maintenance of irrigation equipment. Falsification regressions were also estimated by using the SUR estimator; results are presented in Table A4 in appendix. The perception of reduction in physical water availability did not have a statistically significant effect on any of these ‘false’ outcome variables. These findings further support the relationship between the perception of reduction in physical water availability and current irrigation behaviour.

5. Conclusion

Our results suggest that the perception of reduction in physical water availability in the past can affect farmers’ current irrigation behaviour by increasing the probability of irrigation frequency and the use of self-judgement in determining irrigation need. Results from the heterogeneity analysis show that this effect is more pronounced for smaller farms, farms with sandy soil and farms managed by the owner-managers. It may be easier to perceive reduction in water availability on smaller farms, which may be comparatively more risk-averse than larger farms (Deressa et al., 2009; Kom et al., 2020; Uddin et al., 2014). Sandy soil has higher percolation and farmers might tend to irrigate more frequently or use self-judgement in determining irrigation need on such farms. Managers who are also owners (disproportionately on smaller farms) are likely to be more risk-averse than managers who are not owners, which may reflect in their irrigation behaviour.

Analysis of the relationship between the perception of reduction in physical water availability and irrigation behaviour showed that the relationship subsided for farms that preferred internet-based and in-person approaches for receiving irrigation advice. This finding implies that public irrigation extension services that combine both in-person and internet-based approaches may be helpful in better understanding farmers’ irrigation behaviour.

In an environment where farmers do not receive strong (economic) signals of water scarcity, the perception of reduction in physical water availability and risk of (immediate) agricultural losses is likely paradoxically to encourage farmers to continue irrigating. These results suggest that understanding irrigation behaviour is likely to be important for contextualizing the performance of ongoing policy efforts that are trying to rationalize groundwater management in Jordan.

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Appendix

Table A1. Beliefs about groundwater uses, current levels and future scenarios, by perception of reduction in physical water availability.

Farmers' beliefs (0 to 10: 0=nil or not likely, 10=most likely)	**All farms**	**Farms perceiving reduction in physical water availability**	**All other farms**	**P-value (2-3)**
In the past five years	***1***	***2***	***3***	***4***
Droughts have affected groundwater levels	5.7	6.4	4.7	0.00***
	(0.15)	(0.17)	(0.26)	
In the next five years, groundwater				
levels in my governorate will rapidly fall	4.9	5.8	3.5	0.00***
	(0.17)	(0.21)	(0.25)	
Groundwater levels in my governorate will be affected by farming activities	5.1	5.8	4.0	0.00***
	(0.17)	(0.20)	(0.26)	
My farm income will be lower due to groundwater issues	5.1	6.1	3.7	0.00***
	(0.17)	(0.21)	(0.27)	
Number of farms	**414**	**245**	**169**	

Notes: Point estimates are proportions. Standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively.

Table A2. Relationship of IVs with outcome variables (irrigation behaviour) and the endogenous variable (perception of reduction in physical water availability**).**

Instrumental variables	**More frequent irrigation**	**Self-determined irrigation**	**Perception of reduction in physical water availability**
Beliefs	***1***	***2***	***3***
Droughts have affected the groundwater level in the past five years	0.012	-0.005	0.042***
	(0.008)	(0.008)	(0.008)
Groundwater levels will rapidly fall in the	-0.002	0.009	0.045***
next five years	(0.069)	(0.007)	(0.006)
Groundwater levels will be affected by farming activities in the next five years	-0.006	0.012	0.036***
	(0.007)	(0.007)	(0.007)
My farm income will decrease in the next	0.008	0.007	0.045***
five years due to groundwater issues	(0.007)	(0.007)	(0.006)
Observations	**414**	**414**	**414**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels respectively.

Table A3. Placebo test results.

	More frequent irrigation	Self-determined irrigation
	1	***2***
Perception of reduction in physical water availability *(false)*	-0.014	0.038
	(0.047)	(0.046)
Agricultural loss conditional on perceiving reduction in physical water availability		
Loss of farm income	-0.13*	0.011
	(0.065)	(0.064)
Loss of assets	-0.012	0.023
	(0.076)	(0.074)
Loss of agricultural production	0.13**	-0.033
	(0.060)	(0.059)
Loss of trees	0.017	-0.025
	(0.062)	(0.061)
Controls	Yes	Yes
Constant	0.25	0.27
	(0.23)	(0.23)
Number of farms	**414**	**414**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels, respectively. The 'false' *perception of reduction in physical water availability* variable was created by using a random number generator with normal distribution and a sample mean of 0.59. Additional control covariates include farm manager's characteristics (owner-manager, age, education level, primary job, and residence), farm characteristics (farm size, slope, type of ownership) and farm management practices (registered wells, cultivation status, manager is in-charge for irrigation, number of salaried and family workers, and frequency of meeting between workers and managers).

Table A4. Falsification test results.

	False outcome variables		
	Land holding size	**Access to loan**	**Manager is responsible for drip kit R&M**
	1	*2*	*3*
Perception of reduction in physical water availability	-0.26	-0.089	-0.053
	(0.23)	(0.068)	(0.059)
Agricultural loss conditional on perceiving reduction in physical water availability			
Loss of farm income	0.034	0.044	0.049
	(0.17)	(0.050)	(0.043)
Loss of assets	0.18	-0.0085	-0.090*
	(0.19)	(0.057)	(0.050)
Loss of agricultural production	0.074	0.094	0.096*
	(0.21)	(0.064)	(0.056)
Loss of trees	0.013	0.039	-0.051
	(0.16)	(0.048)	(0.042)
Controls	Yes	Yes	Yes
Constant	3.68***	0.015	0.25*
	(0.54)	(0.16)	(0.14)
Number of farms	**414**	**414**	**414**

Notes: Robust standard errors are in parentheses. Asterisks ***, **, * indicate level of significance at 1%, 5%, and 10% levels respectively.
Additional control covariates include farm manager’s characteristics (owner-manager, age, education level, primary job, and residence), farm characteristics (slope, type of ownership), and farm management practices (registered wells, cultivation status, manager is in-charge for irrigation, number of salaried and family workers, and frequency of meeting between workers and managers).

International Fund for Agricultural Development
Via Paolo di Dono, 44 - 00142 Rome, Italy
Tel: +39 06 54591 - Fax: +39 06 5043463
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www.ifad.org

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ISBN 978-92-9266-119-9