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Public perceptions and perspectives on alternative sources of water for reuse generated at the household level

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ABSTRACT

Studying perceptions about reuse of alternative water sources informs about conditions necessary for transition to large-scale decentralized water reuse. We administered a perceptions survey to the public based on results of initial open interviews of water management experts in Israel. Experts indicated their views on impediments to widespread household water reuse which became the basis for developing the questionnaire. The latter aimed to understand views among the general public of: (a) willingness to adopt reuse practices from three sources: greywater, air conditioner condensate and roof-harvested rainwater; and (b) preferences for targeted use of these three types of reused water. The survey elicited 372 responses. A maximum-likelihood regression analysis was conducted using independent variables (i.e., demographic characteristics, individual positions regarding the state of the country's water resources and plans for the provision of domestic water (i.e., desalination), knowledge of the reuse practices and views about risks from various uses of the reused water, including off-premise uses). Willingness to implement reuse practices served as the dependent variable. We found that respondents indicating that they heard of the reuse of the particular types of reuse practices (variable: 'Knowledge') was the most significant of the independent variables for all three alternative water sources. Also, using an analytic hierarchy process, we determined that health risks were much more important *when compared to* convenience of use and costs under hypothetical scenarios of both moderate and significant savings in monthly water expenditures.

Key words: air conditioner condensate, decentralized reuse, household-generated greywater reuse, household water, public perceptions, rainwater harvesting

HIGHLIGHTS

- Public perceptions inform on willingness to adopt household water reuse practices.
- Our perceptions survey centered on expert-identified impediments to adoption.
- Some attributes of those surveyed were associated with willingness to reuse.
- We found that willingness is associated with previous knowledge of practices.
- Health risk is the most important factor in household-level decisions about reuse.

1. INTRODUCTION

As humans settled into permanent living some 10,000 years ago, waste materials began impacting the environment in proximity to inhabitants' living quarters and changing the nature of essential resources including soil, space, air and of course, water. Today mechanisms that treat wastewater to a high standard abound such that sullied waters can be reused. While reuse technologies that hold little or no risk to users exist, the public is often not ready for them (Miller 2012). The human psyche and socio-institutional factors often imbue greater hurdles than technology which has myriad implications for engineers and planners (Goulden *et al.* 2018; Bohman *et al.* 2020). The conclusion in light of the level of support found by Friedler (2008) among residents of the city of Haifa, and the progress that Israel has made in reuse of domestic water for agriculture (Opher & Friedler 2016) as well as other local water reuse projects in the region (e.g., Faruqui &

Al-Jayyousi 2002) all highlight the need for more current research on perceptions held by household-level users. Such users have a pivotal role in adoption of water reuse practices and long-term implementation of on-site water reuse options.

Among the reasons that residents who have domestic water available to them are reluctant to reuse water, especially greywater, include: real or assumed health risks, mistrust of authorities responsible for minimizing health risk and disgust in the idea – often referred to as the 'yuck factor' (Inbar 2015; Rozin *et al.* 2015; Wade *et al.* 2021). This makes extensive stakeholder engagement and understanding of local water consumers' views and perceptions particularly important (Morgan & Grant-Smith 2015). Some researchers have found that views vary greatly and may be related to cultural factors or to water availability and its cost (Faruqui & Al-Jayyousi 2002; Craddock *et al.* 2021). For some, because of the 'yuck factor', reused water shown to be purer than bottled or tap water will never be considered clean enough for drinking, while others may be quite willing to drink it (Rozin *et al.* 2015).

Studies have shown that the views and perspectives of potential users of recycled wastewater generated in the household influence the adoption of technologies at the household level and beyond (Smith *et al.* 2015a, 2015b; Fielding *et al.* 2019; Amaris *et al.* 2020). Researchers have looked at the willingness to reuse water originating from a wide range of uses and destined for purposes of public or private irrigation (Alataway *et al.* 2011), reuse of greywater within informal settlements (Bakare *et al.* 2016) and on-site greywater reuse in urban areas (Friedler 2008; Gross *et al.* 2015). Others have targeted perceptions of greywater reuse within specific communities, such as among academics and university students (Matos *et al.* 2014) or in developing countries' cities (Akpan *et al.* 2020).

This research seeks to understand how reuse of water generated at the household level is perceived in the vicinity of a peri-urban Israeli city. Beyond household-generated greywater (GWR), which can be recycled using various methods from use of a bucket to collecting shower or dishwater to an in-house treatment and reuse system unit, this study also looks at use perceptions of air conditioner condensate (ACW) generated at the household level, and at the willingness to use harvested rainwater (HRW).

Adoption of such recycling efforts is important, especially when considering urban development needs in the face of warming climates, declining water resources and efforts at increasing sustainability in urban planning and management (Grant *et al.* 2012; Opher & Friedler 2016; Bohman *et al.* 2020). This is particularly true in Israel, situated in the Eastern Mediterranean, considered a hotspot of global climate change and a front-runner in water reuse in the agricultural sector (MedECC 2020). Already in Israel, about 90% of the municipal wastewater is treated in central treatment plants and reused, and of that, more than 80% is used for agricultural irrigation (Dotan *et al.* 2016; Berman *et al.* 2017).

Rising numbers of studies have been performed on public acceptance of water reuse over the past decade using various methods including interviews, questionnaires, focus groups, surveys and discussion groups. These are the most common studies of public perceptions of the reuse of GWR, looking both at acceptable water sources and at uses (Oteng-Peprah *et al.* 2018). Some have researched interventions, such as education (e.g., Wade *et al.* 2021) while others have looked at the role of local governments, especially in the developing world (Faruqui & Al-Jayyousi 2002; Akpan *et al.* 2020; Radingoana *et al.* 2020). With regard to acceptable uses, most found reduction in acceptance as the reused water gets closer to human contact (Oteng-Peprah *et al.* 2018). Shafiquzzaman *et al.* (2018) propose developing an index of public perceptions for water reuse to determine whether reuse infrastructure projects should even be initiated. These trends reflect the importance of psychological factors and contrast with the view of socio-technological impediments are the greatest challenge to widespread adoption of reuse practices (Larsen *et al.* 2016).

1.1. Public perception studies

Research on public perception informs policymaking (Upham *et al.* 2009). The term *public perception* refers to a general commonly held belief or opinion shared by the community, usually formed based on social and cultural characteristics and related to preconceptions. *Public perception studies* that use *surveys*, investigate how people perceive and understand information or situations. Such studies are used to assess general or specific needs and to analyze trends regarding the public's view of the topic investigated assuming that the respondents have agency (Löfstedt 1995).

Several decades ago, the importance of environmental perceptions was highlighted by the adoption of public perception studies as a diagnostic tool by the UNESCO's Man and the Biosphere Program in 1968, declaring such studies a foundation for environmental management (Ishwaran 2012). Since then, public perception studies have been used to better understand the public's position on environmental risks, willingness to practice environmental behaviors, prepare for climate change, and more (Devine-Wright 2005; Hwang *et al.* 2006; Roca *et al.* 2009; Upham *et al.* 2009; Ormerod 2016; Farrugia 2017).

These types of studies are very commonly conducted to understand public willingness or reluctance to practice household-generated water reuse. Studies have investigated public acceptability of water reuse from different sources from sewage (e.g., Smith *et al.* 2018) to harvested rainwater (Mason *et al.* 2018) although most focus on greywater reuse (Inbar 2015). In addition to looking at sources of water, perceptions of various end uses are researched, from large scale irrigation to drinking water (Hwang *et al.* 2006; Miller 2012; Ormerod 2016).

Alataway *et al.* (2011) conducted a study on wastewater reuse in the Kingdom of Saudi Arabia which like Israel, is an arid country with limited freshwater sources. It involved surveying 400 consumers about household wastewater reuse. The study identified the dimensions of acceptability of reuse and developed an 'acceptability scale' based on the survey results. Bakare *et al.* (2016) administered 346 questionnaires on a similar topic to residents of a low-cost housing community in Durban, South Africa. Residents were asked about their attitudes towards household-generated greywater reuse, perceived advantages related to the reuse of household-generated greywater and concerns related to public health. Results revealed a complex and shifting relationship between attitudes toward and perceptions of household-generated greywater reuse.

Matos *et al.* (2014) conducted a study on the acceptance of household-generated greywater reuse among academics from the University of Trás-os-Montes e Alto-Douro Campus (Portugal). The survey included 20 reuse options, which were clustered into three contact levels from distant to close. Regression analysis between the level of support of low (distant), medium and high (close) contact options and demographic characteristics, personal and environmental beliefs was performed. Results show that a high proportion of the participants supported low- and medium-contact reuse options, especially among those respondents with higher education and income. Those with small children at home were generally less willing to adopt reuse practices that exposed residents to medium and high contact with reused household-generated greywater.

Oteng-Peprah *et al.* (2018) presented summaries of quality, system characteristics and reuse strategies for household-generated greywater reuse, particularly in developing countries. They also addressed public perceptions. Regarding the latter aspect, their study showed that user perceptions toward household-generated greywater treatment and reuse were favorable only for non-potable purposes, due to perceived contamination or lack of trust in the level of treatment offered by the available systems. Smith *et al.* (2018) focused on understanding the deeply entrenched 'yuck factor' held by individuals and linked these perceptions with wider societal processes and social representations. Many studies research various aspects of the 'yuck factor', which has been related to responses to the idea of numerous uses of recycled GW, from drinking water (e.g., Rozin *et al.* 2015) to use for large-scale agriculture irrigation (Ricart & Rico 2019). From reviews of reuse response studies, researchers suggest new ways to counter negative perceptions that hinder moving forward with new water reuse technologies.

An important study that looked at a different source of reused water is Ward *et al.* (2012). They used theoretical approaches for suggesting ways to mainstream reuse of harvested rainwater in the UK. The authors report that rainwater harvesting for reuse is widely practiced in Australia, Germany and Japan and at the time (2012) was becoming more common in the UK as a way to achieve sustainable water management. They identified three areas for action: product development, social receptivity and support services through institutional commitment. For householders, they found that awareness of rainwater harvesting as a household water source was relatively low when compared to its use among operators of small and medium business enterprises. Therefore, they recommend capacity building targeting household use for greater implementation.

1.2. Perceptions among Israelis

Israel's experience in water management (Menahem 2001; IWA 2009; Opher & Friedler 2016; Ellis *et al.* 2021) can lead the way forward for countries interested in alleviating drinking water scarcity. The Israeli population has dealt with water shortages for decades. Beginning in the 1990s, Israel has become densely populated (averaging 366 persons/km^2) and highly urbanized with >90% of the population currently living in cities (ICBS 2013, 2018). For some time now, Israel reuses over 80% of its treated wastewater effluent, mostly through centralized municipal wastewater treatment plants and regional reuse schemes for agricultural irrigation (IWA 2009).

To overcome freshwater shortage, Israel developed a seawater desalination scheme with a capacity of approximately 600×10^6 m^3/y in the year 2016 and for double that by 2050. However, for urban areas, desalination can only be a partial solution; its costs are high to the end user and to the environment. The full impacts of seawater desalination to the marine environment as well as the sensitivity of intake water to marine pollution are still unclear (Grossowicz *et al.* 2020). To avoid the need for total reliance on desalination, household demand should be reduced using all available technologies and practices.

Ellis *et al.* (2021) attribute Israelis high willingness to pay (WTP) for food grown using alternative water sources (defined as any water source other than conventional ones, such as groundwater and treated surface water, including desalinated seawater and recycled household wastewater) to the fact that Israel, has been using alternative irrigation water on a nationwide scale for over three decades. Yet, Ellis *et al.* (2021) also point out that surprisingly few studies have investigated Israeli consumers' perceptions of this reuse strategy.

In an international comparative study, Messer *et al.* (2018) point out that Israel's severe water shortage is responsible for Israelis' high overall familiarity with the use of nontraditional water sources resulting in a higher WTP for produce irrigated with different types of nontraditional water when compared to other populations. From conducting a comparative analysis of perceptions of different uses of alternative water in nine different countries, Hurlimann & Dolnicar (2016) found that Israelis preferred recycled water over desalinated water for water plants and toilet flushing. In this comparative study, recycled water was also preferred by Israelis for cleaning but not for drinking.

Apposite past studies that address perceptions of domestic water reuse in Israel include Friedler (2008), Inbar (2015) and Opher & Friedler (2016). Several leading themes portray the Israeli public perceptions toward domestic water reuse (Inbar 2015). The level of physical contact was shown to play an important role in the degree of public support of domestic water reuse. Friedler (2008), which focused on willingness to reuse GW, found the public highly supportive of the reuse options suggested, with an overall average grade of 85%. The six reuse options were: sidewalk landscaping, public parks irrigation, office toilet flushing, commercial car wash, private garden irrigation and domestic toilet flushing. Overall, Israelis were found to be supportive of public water reuse more than reuse in their homes, e.g., GW use for toilet flushing in office buildings received higher average grades than toilet flushing in the home (Friedler 2008).

There are other pertinent studies directed at the adoption of other water-related practices designed to improve efficiency, help achieve urban sustainability and counter climate change effects (Teschner *et al.* 2012; Goulden *et al.* 2018). Such studies have emphasized the socio-technical challenges related to water reuse and management in urban settings. Practices of sustainable stormwater management in Israel have been recently examined as part of a KKL-JNF campaign, promoting green infrastructure (Alon-Mozes *et al.* 2020). Other studies have looked for differences in willingness to consume reused water by Palestinians and Israelis (Craddock *et al.* 2021) or compared compounds found in wastewater treatment between in Israel and the Palestinian West Bank (Dotan *et al.* 2016).

Goulden *et al.* (2018) report that for transition to new practices sustainable water management, impediments fall under the general categories of being cultural-cognitive, normative and regulative impediments. Teschner *et al.* (2012) researched transitions to sustainable use and management in the water and energy sector stating that Israel has addressed its water shortage issues by 'traditional supply side solutions such as seawater desalination'. It is likely that household water supply generated by desalination is an impediment to urban water reuse measures in Israel because it reduces the incentives and the need for water reuse and water conservation in general. When there is a dire need for water due to shortages, conservation practices such as those researched here become essential and willingness to reuse water goes up. To highlight this point, we see that shortages are exacerbated by geopolitical conflict. Craddock *et al.* 2021 found that willingness to reuse household wastewater was associated with water shortages which are more common among the Palestinians living on the West Bank, than among Israelis.

The study presented here seeks to inform about impediments to alternative water use among a random sample in the Israeli context while building on previous studies in Israel and abroad. Our investigation of household user perceptions and attitudes consists mainly of a survey administered to residents and visitors in the suburb of Kfar Saba and to the Israel public at large (convenience sample). Kfar Saba is a town in the center of the country with a population of approximately 110,000 (ICBS 2018). It is a mid-level income town that attracts visitors from neighboring areas for shopping and various regional services not available in smaller settlements in the center of the country. It has a hot Mediterranean climate. The Israel Meteorological Service (IMS) reports temperature data from a measuring station closest to Kfar Saba (Karnei Shomron) for years 1995–2009. At that station, average temperatures in January ranged between maximal to minimal 22.8–3.1 °C and in August 34.1–18.3 °C. The average yearly rainfall for the period 1995–2009 was 636 mm (IMS 2021), with wet winters and completely dry summers.

2. METHODS

This study used a mixed-methods approach to determine associations between various aspects of public perceptions, related socio-economic conditions and willingness to adopt alternative water reuse practices of three types: harvested rainwater,

greywater and AC condensate. The concern is for water generated at the household level although respondents to the questionnaire were asked about channeling such reused water to some public uses, i.e., in public toilets and for public park irrigation.

The first step consisted of in-depth interviews of key informants regarding what they view as the main impediments and opportunities for alternative water reuse at the urban household level in the Israeli context. Open-ended questions were devised by the research team to elicit experts' response, while initial contacts were made with experts selected because of their professional capacities in organizations and government agencies working on water management issues in the country.

Ten experts, that included researchers, municipal planners and regulators (see Table 1), were asked for their opinions on household-generated greywater and rainwater harvesting in Israel, including health, legal and economic ramifications, and the possible barriers to further implementation of these water reuse practices in Israel. We asked about key points, ideas and concepts related to household water reuse. As recommended for an in-depth qualitative survey approach (Reed *et al.* 2009; Patton 2015), we transcribed and analyzed the content of interviewee's answers, coded and fitted them to categories and sub-categories by themes (hereafter 'thematic analysis') using open coding. Codes are iteratively united under one of the sub-categories until no new concepts are found in the interview text.

Key points and categories gained from the qualitative assessment (Figure 1, Results) informed the different sections of the householder questionnaire (hereafter 'the survey') administered using a random sample and convenience sample approach (Schonlau *et al.* 2002; Wright 2017). The public perceptions questionnaire was designed with the general household water end-users in mind. Survey questions were similar to questions posed previously by Friedler (2008) and Opher & Friedler

Table 1 | Experts interviewed by sector and professional affiliation

Sector		Professional Affiliation	Number of Interviewees
Government	National level	Ministry of Health	1
		Ministry of Environmental Protection	1
		Water Authority	2
	Municipal level	Water Corporation	1
Private Sector		Infrastructure	1
		Water Management/Consultant	2
Academic Researchers			2
Total			10

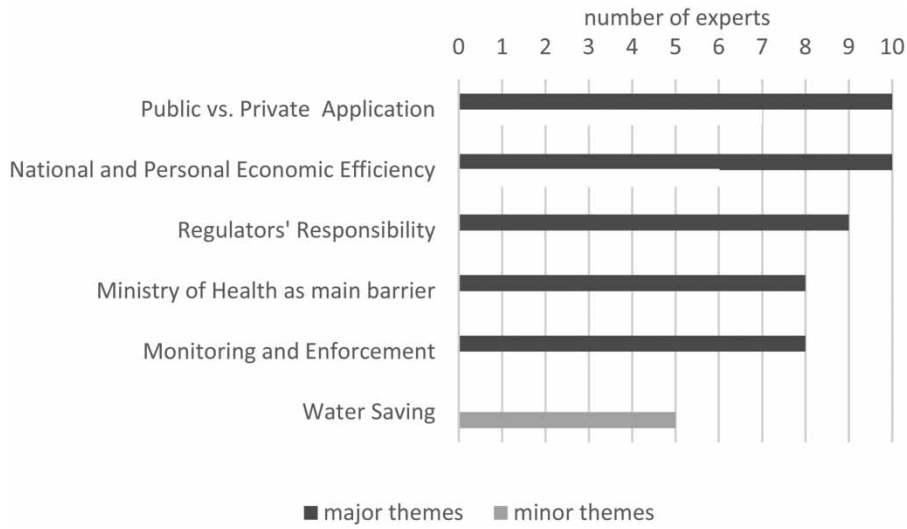

Figure 1 | Number of experts mentioning those themes deemed important to consider in the larger survey. Darker and lighter gray indicates themes of major concern and minor concern, respectively.

(2016) with some adjustments due to new or neglected categories that were developed based on the in-depth interviews and literature (Bakare *et al.* 2016; Mankad *et al.* 2019).

The survey consists of 36 questions (see Supplementary Material, Appendix 1) arranged in six sections: (a) perceptions of water supply and reuse, (b) water consumption habits, (c) trust in responsible authorities, (d) willingness to pay, (d) a scenario comparison section (using pairwise comparison of three factors) and (e) biographical details. At the beginning of the questionnaire, a brief description of the research objectives was provided, as well as short definitions for three types of water. The penultimate part of the questionnaire (topic 'd' above) uses pairwise comparison analysis as developed by Saaty (1977). This approach, usually referred to as the Analytical Hierarchy Process (AHP), is used for the weighting of criteria for decision making under varying scenarios.

During October–November 2019 (following receipt of permission no. 2019-026 from the Behavioral Sciences Research Ethics Committee, Technion's Institutional Review Board), two surveyors collected in-person hard copy responses from residents and visitors in Kfar Saba. Respondents were random passersby at pre-defined locations (a central shopping center and busy central corner) who agreed to answer the questionnaire. The surveyors were instructed in advance to assist respondents with general questions regarding the survey, and to refrain from explaining any water-related concepts beyond the written explanations in the survey. Additionally, a digital online survey identical to the print version was created using Google Forms and available through a link distributed by research team members via social media and e-mail. The two survey types, the digital and hard copy, are identical in form and substance. These two groups are later referred to respectively as those answering a printed or digital copy of the questionnaire (see Results).

We sought to model the variables associated with the willingness to reuse each of the three alternative water sources. Respondents were asked how willing they would be to reuse each of the water types '… after being assured that there are no health risks' (see Part B of the questionnaire). The independent variables were taken from all parts of the questionnaire, except for the 'Scenario Comparison' portion (Section D.5.1-2 in Questionnaire, see Supplementary Material, Appendix 1), which was analyzed separately.

The independent variables used for the modeling were: perceptions of water scarcity in the country (a recoded version of questions A.1–A.3), respondents' position on the country's desalination plan, 'knowledge' of different alternative use practices, the level of trust in a responsible authority for water reuse (question C.1), various socio-economic and demographic variables and a 'group' variable indicating whether the respondent answered the online or the hard copy of the questionnaire. Socio-economic and demographic variables included age, gender, number of persons in the household, number of children in the household, level of education, income level, town of residence, type of residence, house ownership and water bill payments in relation to average national per person monthly expenditure for water.

Knowledge, which ended up being a significant variable in some of the modeling, is the term used for the variable arrived at through asking whether the respondent had 'heard of' GWR reuse, ACW reuse or reuse of HRW (question A3). We use this as a general term with the assumption that having heard of the practice, respondents have varying levels of knowledge, awareness or familiarity with the practice.

A stepwise ordinal logistic regression model was first tried. The running of a stepwise ordinal logistic regression model for all the dependent variables using the original ordinal variable with five levels (absolutely willing, willing, probably not willing, absolutely not willing and 'I don't know') violated the proportional odds assumption. Similarly, fitting separate parameters for the predictors across all four logits of the response lead to an invalid, non-convergent model due to the large number of variables and interactions. This required the recoding of responses (to questions B1.1–B1.3, see Supplementary Material, Appendix 1) such that a negative or a don't know answer (categories 1, 2, 3) became '0' and a positive answer (categories 4, 5) became '1'. A stepwise logistic regression model was fit and the three global tests (Likelihood ratio, Score and Wald) lead to the rejection of the null hypothesis that the explanatory variables are unrelated to the new binary variable; this suggests that the model explains a significant amount of variation in the data. As mentioned, we analyzed the printed, hard copy surveys separately from those responses received from the digital survey. The differentiation resulted in an additional explanatory variable: Group = printed and Group = digital.

As for determining the willingness of respondents to use the three alternative water sources for different purposes (questions B2.1–B2.3), increasing risk levels were ranked from 1 to 5 (5 = highest risk level). The cumulative total gave an indication of the willingness to bear risk for each of the particular alternative water sources. Risk levels for each use (Table 2) are based on various secondary sources (e.g., Marks *et al.* 2003; Friedler *et al.* 2006). Stepwise logistic regression models were run using this variable for each water source type.

Table 2 | Five possible uses for each water type and corresponding risk levels

Water use	Risk level (1 – minimum; 5 – maximum)
Public and work toilets	3
Home toilets	2
Laundry	1
Watering parks	5
Watering private yards	4

In Parts D.5.1 and D.5.2 of the questionnaire (see Supplementary Material, Appendix 1), respondents were asked to indicate the importance of three decision parameters under two scenarios: (a) 25% saving on the monthly water bill and (b) 75% saving on the monthly water bill. For this part, the AHP was deemed appropriate since it has been used in past in studies comparing wastewater treatment types (e.g., Ouyang *et al.* 2015).

To keep the questionnaire as short as possible, we consolidated the pairwise comparisons into three questions for each of the two scenarios for a total of six questions. Respondents ranked whether (a) health risks, (b) convenience and ease of use or (c) system installation and maintenance costs would be a lot more important, slightly more important or the same to them in deciding to install a 'reuse system'. Eigenvectors of the matrices extracted from their answers gave the scalar weights which were then averaged for all respondents.

3. RESULTS

The most frequent themes identified in the stakeholder interviews are listed in Figure 1 according to the number of experts who mentioned them. Only those recurring themes mentioned by at least half of the experts are considered. The top five recurring themes indicated as major concerns were: public vs private application; national and personal economic efficiency; regulator efficacy; the Ministry of Health regulatory prohibitions and efficacy of monitoring and enforcement. The last theme, referring to the issue of water savings, is considered minor as it was mentioned by only half of those interviewed (see Figure 1).

'Public vs private application' indicates that the use context is a major concern in determining the willingness of the public to adopt household reuse practices. The second most frequently mentioned theme refers to the costs of transitioning to domestic water reuse. Following that, concerns about regulators' ability to ensure health and safety was identified. Whether the public trusts the regulator to sufficiently monitor and enforce sufficient water quality standards and the fact that the Israel Ministry of Health prohibits the use of such systems at this time were both mentioned by the same number of experts as themes of major concern. This last major theme resulted in the researchers asking the public respondents only about hypothetical future reuse since currently the Ministry of Health prohibits reuse. The next coded theme mentioned by half of the experts interviewed was 'water saving' referring to the significance of the potential for water conservation. As mentioned in the methods section above, these themes influenced the design of the large-scale public survey.

Two hundred and twenty persons responded to the digital online survey which together with the 146 printed surveys answered totaled 366 responses. Respondents varied from 18 to 87 years of age; the mean age of respondents to the printed survey was 58 (sd = 17) and to the digital survey was 41 (sd = 12) ($p < 0.0001$). For the printed and digital surveys, respectively, 57% and 50% of the respondents answered female and 43% and 50% answered male.

For several categorical and ordinal variables (type of housing, home ownership, education level and income), the difference between the printed and digital answers is statistically significant (Table 3). Overall, we assume that, unsurprisingly, respondents to the digital survey are a 'stronger' population, better-off economically, with higher levels of education. Ninety-one percent of the digital survey respondents indicated holding an academic degree while only 56% of the printed survey respondents indicated having obtained an academic degree.

3.1. Predicting perceptions: use of alternative water sources

Next stepwise logistic regression models were fitted relating perceptions of the water supply, familiarity with reuse practices and other variables (categorical and ordinal) to the willingness to adopt each of the three practices: reuse of (a) household-generated

Table 3 | Descriptive statistics summary of quantitative, categorical and ordinal variables of the survey respondents

	All Respondents ***N*** **= 366**	**Printed** ***N*** **= 146**	**Digital** ***N*** **= 220**	***p*-value of difference***
Age – mean	47.6	58.4	40.5	**<0.0001**
(Standard deviation)	(16.7)	(16.9)	(12.2)	
	Number (%)	Percent of group		
Gender				0.23
Female	194 (53%)	57%	50%	
Male	172 (47%)	43%	50%	
No. of persons in household				0.0567
1	33 (9%)	11%	8%	
2	113 (31%)	36%	28%	
3	77 (21%)	20%	21%	
4	78 (21%)	19%	23%	
5	51 (14%)	12%	15%	
6	12 (3%)	1%	5%	
7	2 (1%)	1%	0%	
Housing unit type				**0.0001**
≥5-floor apartment building	54 (15%)	21%	11%	
<5-floor apartment building	169 (46%)	49%	44%	
Duplex	43 (12%)	3%	17%	
Single-family home	100 (27%)	27%	28%	
Housing unit owner				**0.0265**
No (rent or live with parents)	151 (41%)	34%	46%	
Yes	215 (59%)	66%	54%	
Education				**<0.0001**
Highschool	43 (12%)	24%	3%	
Professional	42 (11%)	20%	6%	
BA	157 (43%)	40%	45%	
MA/PhD	124 (24%)	16%	46%	
Income (NIS)**				**0.0224**
Below 10,000	109 (30%)	38%	25%	
10,000–18,000	113 (32%)	23%	37%	
18,000–30,000	112 (31%)	32%	31%	
Above 30,000	25 (7%)	7%	7%	

*Values in bold indicate a statistically significant difference.

**Net average household income in Israel ~16,500 New Israeli Shekel/month (ICBS 2017).

greywater reuse (GWR), (b) air conditioner condensate water (ACW) and (c) harvested rainwater (HRW). The analysis of the maximum-likelihood estimates for each of the alternative water types are provided in Supplementary Material, Appendix 2.

A more convenient interpretation of the models uses odds ratio estimates (Table 4). The significance of the odds ratio is tested against the value 1, so that confidence intervals that do not contain 1 denote significant effects. An odds ratio of <1 means lower chances of a positive response with regard to willingness to reuse the alternative water source as the value of the independent variable increases.

For GWR, an increase in one unit of 'Knowledge' (indicated based on answers to Question A.3 on whether the respondent has heard of GWR/ACW/HRW, thus ranging from '0' no knowledge to '3' for familiarity with all three concepts) is associated

Table 4 | Odds ratio estimates and Wald confidence intervals for explanatory variables for GWR, HRW and ACW (only significant and marginally significant effects are presented; see Supplementary Material, Appendix 2)

Effect	Estimate	95% Wald confidence limits	
Greywater Reuse (GWR)			
Knowledge	3.041	2.046	4.519
Income	0.644	0.455	0.912
Desalination_pos at Group = printed[a]	2.411	1.307	4.447
Air Conditioner Condensate Reuse (ACW)			
Knowledge	4.100	2.506	6.709
AVG_A1_A3 at Group = digital[a]	0.167	0.054	0.521
Age at Group = printed[b]	0.986	0.959	1.013
Age at Group = digital[a]	1.060	0.995	1.129
Harvested Rainwater Reuse (HRW)			
Group printed vs digital[b]	0.481	0.226	1.024
Knowledge	1.808	1.188	2.752

[a]Independent variables 'printed' or 'digital' indicates separate analyses for each of the survey versions.
[b]Marginally significant difference between printed and digital respondents in willingness to adopt this practice.

with a 3.041-fold increase in the odds of indicating a willingness to reuse household-generated greywater ($p < 0.05$). An increase in one unit in the income category (ranging from low to high income) is associated with a 0.644-fold reduction in the odds of indicating a willingness to reuse household-generated greywater in the home, reflecting a lower chance of a positive response. From among the printed survey responses, a more positive perception of the country's plan for water desalination is associated with a 2.411-fold increase in the odds indicating willingness to reuse household-generated greywater ($p < 0.05$). For the digital survey responses, a positive perception of Israeli desalination is not significantly related to the willingness to reuse household-generated greywater.

With regards to reusing ACW, a higher 'Knowledge' level is associated with higher chances of indicating a willingness to reuse air conditioning condensate (Odds ratio (OR) = 4.1, $p < 0.05$). Respondents are less likely to indicate willingness to reuse ACW if they hold a positive view of the state of the water supply in Israel (OR = 0.167). This seems intuitive; as people believe the situation to be more dire, they are willing to commit to using alternative water sources, in this case ACW. However, only the responses from the digital surveys showed significance in this regard. Age for both type of surveys, digital and printed, showed marginally significant effects (and, therefore, Age is included in Table 4).

Finally, with respect to HRW reuse, greater 'Knowledge' is associated with higher chances of being willing to reuse HRW (OR = 1.808). Also, respondents of the printed survey were less likely to give a positive answer regarding their willingness to reuse HRW compared to respondents to the digital survey (OR = 0.481). The confidence level in this case showed marginally significant effects.

3.2. Risk level analysis

Statistical analysis of the responses to the portion of the survey that asked about willingness to reuse the GWR/ACW/HRW for various purposes, leads to two sets of results. The first was the simple statistical calculation of percentages of respondents indicating willingness to reuse each water type for one or more of the uses associated with different risk levels (Table 2). The second risk level analyses were conducted by fitting a stepwise logistic regression model to the end use (purpose) of each water type.

Generally, it seems that respondents believe that greater risks are associated with reusing water of all three types in the home, either for flushing toilets or for laundry (Figure 2). The greatest risk is perceived from the use of household-generated greywater for laundry, with the use of HRW and ACW also perceived as being risky compared to reuse of these types of water for other purposes.

The results of the stepwise logistic regression model that was fitted to each water type point to several significant variables. Most of the independent variables, which are the same ones used in the logistic regression for the prediction

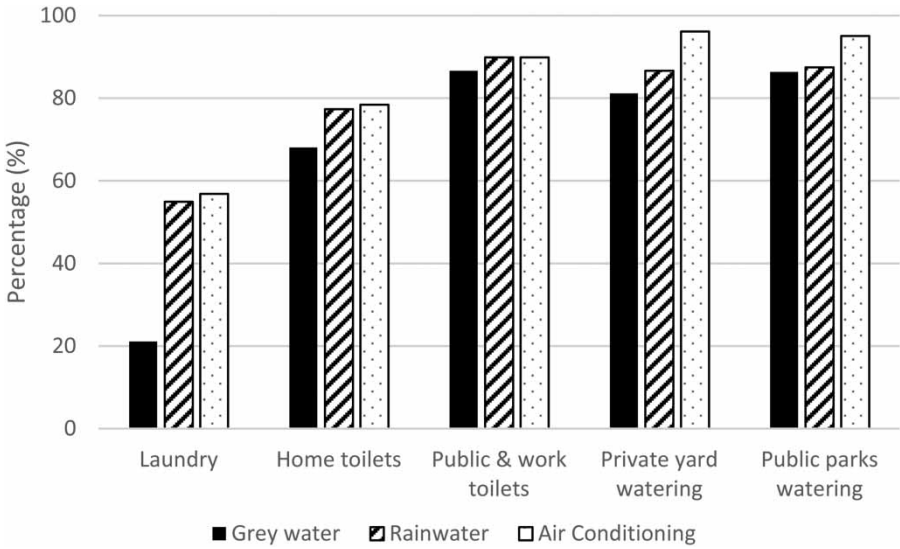

Figure 2 | Percent of respondents willing to reuse water of different types for five purposes as indicated in both digital and printed versions of the survey.

of use of the three water types described above, were not found significant in predicting willingness to use the different practices.

The model fitted for GWR included the most variables. Of these, 'Knowledge' again appears to be important: a high level of knowledge, as indicated by familiarity with practices of reuse of GWR/ACW/HRW, was associated with an increase in the odds of willingness to use greywater for public and work toilets (OR = 1.864), for home toilets (OR = 1.522) and for laundry (OR = 1.48). Even for watering parks and private yards (OR = 2.74 and OR = 3.093, respectively), Knowledge is a significant variable. However, this result was only found among the printed survey responses. Furthermore, trust in authorities (C.1 in the questionnaire) is associated with higher odds of willingness to reuse household-generated greywater for toilets in public spaces and at work. Finally, people are less likely to use household-generated greywater in home toilets as their perception of the state of water supply in Israel improves from very bad to excellent.

Few relationships could be confirmed between willingness to reuse ACW for various purposes and the independent variables. From the statistically significant associations (see Table 5), trust in authorities is associated with higher odds of willingness to use ACW in public and work toilets (OR = 2.841), however this result was obtained only from responses to the printed survey. People are less likely to use ACW in home toilets (OR = 0.297) and for laundry (OR = 0.686) as their perception of the state of the country's water supply improves. The opposite is true with regards to their perception of the water desalination projects; a positive perception of the country's large-scale desalination projects is associated with a greater likelihood to use ACW in home toilets (OR = 1.546). Lastly, those who own their home are less likely to agree to use ACW for watering parks when compared to non-owners (OR = 0.069).

Like ACW reuse results, few associations were deemed statistically significant for the odds ratio indicating willingness to reuse HRW for various purposes. The model indicates that people are less likely to reuse rainwater for home toilets (OR = 0.394) and for laundry (OR = 0.507) as their perception of the state of the country's water supply improves, but this result was only obtained in the printed survey. Similarly, a more positive perception of large scale desalination is associated with an increase in the odds of using rainwater for home toilets (OR = 1.796), for laundry (OR = 2.097) and for watering of private yards (OR = 1.977). However, the latter two ORs were found only among printed survey responses. Finally, the odds of being willing to reuse rainwater for home toilets decreased with Age (OR = 0.979).

3.3. Importance of decision-making factors

Section 5 of the survey (Supplementary Material, Appendix 1) revealed weights for deciding to install a household reuse system under two hypothetical scenarios by comparing three factors: health, convenience and cost. The first scenario consisted of a

Table 5 | Odds ratio estimates and confidence intervals of those independent variables that show significant effects

Water use	Effect	Estimates	95% Wald confidence limits	
Greywater Reuse (GWR)				
Public & work toilets	Knowledge	1.864	1.238	2.808
	Trust in Authorities[a]; Group = printed	2.621	1.331	5.162
Home toilets	Natural water supply perception[b]	0.394	0.278	0.558
	Knowledge	1.522	1.087	2.132
	Age; Group = printed	0.955	0.932	0.979
Laundry	Knowledge	1.480	1.002	2.187
	Age	0.964	0.944	0.983
Watering parks	Knowledge; Group = printed	2.740	1.308	5.738
Watering private yards	Knowledge; Group = printed	3.093	1.676	5.706
Air Conditioner Condensate Reuse (ACW)				
Public & work toilets	Trust in Authorities; Group = printed	2.841	1.327	6.081
Home toilets	Natural water supply perception[b]	0.297	0.196	0.449
	Group printed vs digital	3.149	1.289	7.691
	Desalination program perception[c]	1.546	1.059	2.257
	Age	0.974	0.955	0.993
Laundry	Natural water supply perception	0.686	0.518	0.908
	Group printed vs digital	2.102	1.113	3.970
	Age	0.976	0.962	0.992
Watering parks	House ownership	0.069	0.009	0.548
	Desalination program perception[c]; Group = digital	0.605	0.240	1.526
Watering private yards	None of the variables is significant			
Harvested Rainwater Reuse (HRW)				
Public & work toilets	None of the variables is significant			
Home toilets	Natural water supply perception[b]	0.394	0.287	0.541
	Desalination program perception[c]	1.796	1.246	2.587
	Age	0.979	0.962	0.996
Laundry	Natural water supply perception[b]; Group = printed	0.507	0.341	0.755
	Desalination program perception[c]; Group = printed	2.097	1.266	3.474
Watering parks	Group printed vs digital	2.933	1.364	6.308
Watering private yards	Desalination program perception[c]; Group = printed	1.977	1.090	3.588

[a]Responses to question (Q) C1 indicate the respondent's trust in the Israeli authorities' ability to ensure a clean and healthy domestic water supply.
[b]Responses to Q A1 and Q A3 on a scale of 1–5 were averaged to indicate perceptions of the domestic supply of water from natural sources (from 'excellent' to 'very bad').
[c]Responses to Q A2 indicate perceptions of Israel's plans to solve its domestic water supply problems by large scale desalination; therefore, a positive response, on a scale of 1–5, indicates support for large scale desalination.

25% reduction in monthly water bill from a water reuse system and the second consisted of a 75% reduction in monthly water bill (Figure 3).

The results show only slight differences between the responses to the different scenarios. Clearly, the most important factors from among those suggested that would determine whether or not a respondent would be willing to use the system, was that of health; health concerns made up the most important factor under both scenarios as per responses to both the digital and printed versions of the survey.

Differences between the factors compared were slightly more pronounced in the printed versions than in the digital responses. In the digital survey, under the first scenario, convenience and cost were equally important factors, both less important than health. In the printed version, under both scenarios, health concerns far outweighed concerns about convenience and costs of the reuse system.

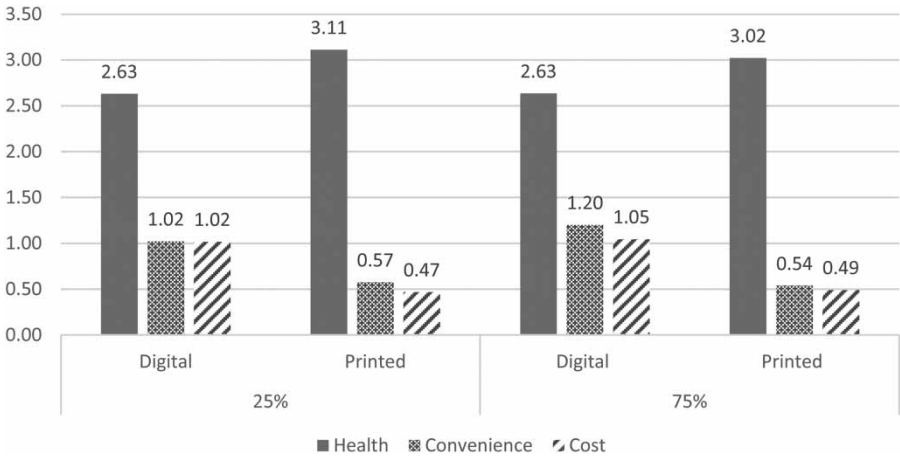

Figure 3 | Final weights resulting from the pairwise (AHP) comparison indicating the relative importance, based on eigenvalues, of three decision-making factors (health, convenience and cost) compared by respondents (see Section D, Supplementary Material Appendix 1).

4. DISCUSSION

The findings from our survey supplement the general scholarship seeking to understand the conditions necessary for rapid and wide installation of household water reuse systems. For any source of 'used' water, but particularly for household-generated greywater, the 'yuck' factor must be considered (Smith *et al.* 2018). This factor often pertains to the reluctance to use or have contact with what is considered impure water generated in and around households (Miller 2012; Inbar 2015).

The results present two interconnected issues – those related to (a) the sources of reuse, in this case GWR/ACW/HRW and (b) the purposes or end use of the water. Perceptions of the public for both must be well understood. Public perceptions, attitudes and behavior could invariably lead to decision making with regard to alternative water reuse by residents at the household level (Hurlimann & Dolnicar 2010; Inbar 2015; Smith *et al.* 2018) but could also generate political will for policy changes needed in the country since Israeli law does not allow reuse of household water. Understanding perceptions is also essential for planning of incentivization schemes (Jacobs *et al.* 2016). Understanding differences between public perceptions and those of professionals is a first step toward communicating knowledge and information to the public. This may be a first step toward 'harnessing' the public toward water reuse practices.

The general municipal or regional context is important as cultural, socio-economic and legal factors of the population being studied are invariably quite different (Jeffrey & Jefferson 2003; Friedler 2008; Alataway *et al.* 2011; Miller 2012; Ormerod 2016; Gao *et al.* 2019; Lu *et al.* 2019), even within the same country (Amaris *et al.* 2020). In this study, the most important findings are based on correlations between salient characteristics of the surveyed population and the information about the end uses that would most likely be acceptable to them for each of the three alternative water sources.

4.1. The water sources

Regarding the water source to be reused, the analysis of differences in responses for GWR/ACW/HRW gave limited results. The most significant predictive associations were for household-generated greywater. Further study should consider different options for where such household-generated greywater comes from. In our study, only in-house water was considered. Jeffrey & Jefferson (2003) asked respondents about their willingness to use off-site greywater, such as from service areas near motorways or hospitals. In that study, higher rates of acceptance of use were indicated by a larger percentage of respondents from nearby (next door) house.

Health and safety were the greatest concern about household-related reuse in general without differentiation between the three sources. 'Health' came out far ahead when compared to 'Cost' and 'Convenience' in both the printed and the digital versions of our survey. Even major savings in potable water supply cost to households do not seem to impact this priority in decision making on the household level.

4.2. Acceptable uses

Regarding suitable *uses* for alternative water sources studied, both similarities and differences with previous studies were found. Alataway *et al.* (2011) who studied public perceptions to general 'wastewater reuse' found the order of decreasing concern for different use types to be: agricultural use, household use and public use. This coincides with findings of Friedler (2008) who found in a study of 256 respondents in Israel that people were more supportive of household-generated greywater reuse in public places than in their homes, yet contrasted with the finding of this study with relation to reluctance to use greywater for laundry. Despite health risks being low for the reuse of water for washing clothes (Table 2), respondents to this study indicated a particular aversion to that use. Although willingness to use HRW and ACW for doing laundry were higher than household-generated greywater, for all three sources willingness is lower than for toilet use and for use in gardens both public and private.

These results contrast with results of other studies. Particularly, Jeffrey & Jefferson (2003) report that an exploratory study conducted on the general British population, based on a representative sample of 300 survey respondents that 88% were willing to recycle household-generated greywater (from showers and baths) for flushing home toilets. The study by Amaris *et al.* (2020) on residents in Santiago, Chile, indicated an overall acceptance in decreasing order of preference for using high quality treated household-generated greywater for toilet flushing, laundry, garden irrigation, hand washing and shower/bathtub use. The differences in these outcomes, reinforces the importance of context and of conducting parallel studies among divergent populations in different geographic regions.

4.3. The importance of knowledge and income

The result of the present study shows that 'Knowledge' of water reuse practices, is associated with a stated willingness to adopt any of the three water reuse practices. Other studies which have rating preferences using a Likert-type scale (e.g., Alataway *et al.* 2011) or using discrete choice experimentation (e.g., Amaris *et al.* 2020) have come to similar conclusions. A factor that is similar to knowledge about reuse, perhaps better termed 'familiarity', could be surmised from Lu *et al.* (2019) who found that households in Boston, Massachusetts, USA, were more likely to adopt a decentralized water facility that included rainwater harvesting if their neighbors had already installed one.

The likelihood of wealthier respondents being less interested in household-generated greywater reuse is surprising. First of all, it seems that higher earning respondents would be more amenable to the adoption of a reuse system but it also might be that they have little or no concern about water savings. In any case, cost and even inconvenience were not considered important factors under either of the two scenarios asked about using AHP (Figure 3), suggesting that water savings does not matter much among respondents in general. The low cost of water in Israel (2.15 US$/m^3 for the first 3.5 m^3/(person·month), then 3.92 US$/m^3; November 2020) is well documented (Menahem 2001; IWA 2009; Opher & Friedler 2016). It could be that those who did give weight to the costs of adopting reuse systems and who indicated slight preferences under the two scenarios, were relatively low-income respondents.

Greater reported knowledge seems to be associated with greater willingness to use recycled water. However, higher income seems to have the opposite effect, yet higher income people tend to be more educated. Alhumoud & Madzikanda (2010) in an article on public perceptions of using recycled water in Kuwait, found that education levels are associated with greater willingness to use recycled water. So, our study shows an interesting contradiction with regard to income, assuming that better educated people are wealthier. However, it does seem intuitive that there would be less interest in water savings for financial reasons among wealthier, and perhaps more educated, residents.

Another interesting factor is related to perceived water scarcity. Similar to findings of this study, Lu *et al.* (2019)'s study of water reuse in two US cities, including rainwater harvesting practices found that households are more likely to adopt decentralized water reuse if they perceive water scarcity. However, in our study, the association between perceptions of the state of the 'natural' water supply (i.e., a concern for the need to conserve water) and willingness to adopt reuse practices was only found definitively for ACW. More study is needed to understand why this is so. It may be due to the age of those most willing to reuse ACW because older respondents were exposed for many years to massive communication about water shortages in Israel. The dependence on desalination is a relatively new phenomenon, and other (possibly political) factors, have lead to less emphasis on communicating to the public about water shortages.

4.4. Institutional factors

Study findings from the public survey contrasts with what was found from the in-depth interviews of Israeli water management experts who frequently indicated institutional issues such as compliance and enforcement and raised concerns about the role of the Ministry of Health in advancing water reuse practices. The public perceptions survey respondents did not indicate clear positions about their trust or mistrust in authorities to monitor and regulate decentralized reuse systems. While it is likely that experts' concerns about responsibilities for advancing water reuse on a household level probably reflect their role as professional water use managers, analysis of the in-depth interviews did indicate an understanding that centralized institutions must be involved for change on the household level.

When considering overall government policy with regard to new water technologies, especially at the household level, there must be sensitivity to socio-technical aspects of acceptance, willingness-to-adopt and political-administrative responsiveness and accountability (Jeffrey & Jefferson 2003; Hurlimann & Dolnicar 2010; Inbar 2015; Pakizer & Lieberherr 2018). Currently, there is no official policy promoting household reuse of water in Israel. Yet, in light of the local and global changes in the water cycle, the deterioration of natural water sources and effects related to climate change, it is necessary to consider promoting policies sooner rather than later.

For many years, the focus of water management and particularly reuse of water for conservation purposes in arid and water-tight environments has been on the agriculture sector (Alataway *et al.* 2011; Miller 2012). This definitely applies to Israel, where more than 80% of the treated municipal wastewater is reused for agricultural irrigation for years (IWA 2009). However, urban water management has recently gained more attention, in part due to the comprehensive Sustainable Development Goal on Water (SDG 6) (United Nations 2020) but also due to salient climate change effects. The generally accepted approach to urban water management builds on well-established socio-technical systems that at least in affluent countries, have solved many of the water and hygiene-related problems prevalent in cities from the turn of the 20th century (Larsen *et al.* 2016).

Especially in Israel, decentralized water reuse systems employed at the household level could greatly impact water savings and reduce dependence on large scale desalination with all its economic and environmental costs (e.g. Grossowicz *et al.* 2020). Friedler (2008) optimistically forecast that a realistic penetration ratio of domestic household-generated greywater by 2025 in the country could lie in the range of 19–31%, leading to a national water saving potential of 30 to 51×10^6 m^3/y. While more than a decade after that estimation, it seems that Israel is far from such savings. Therefore understanding impediments, drivers, motivations and concerns of the public about both the sources and possible uses of reused domestic water is essential.

While there are a number of limitations to this study, there are still important lessons learned. One of the limitations is that some assumptions have backed up the questions asked in the survey. The authors have assumed that a respondent more supportive of water desalination will be less motivated to reuse any of the three types of water (GW, ACW and/or HRW). This, in fact, was backed up by the findings at least for GWR (see Table 4 and Supplementary Appendix 2).

There are also some methodological limitations related to the order of the questions, which may have been confusing (e.g., question B starts out by assuring the respondents that there would be no health risks to reusing GW) but that statement is valid only for part B. The area of residence is likely linked to socio-economic attributes of the population. Furthermore, the questions are on disparate topics (single items), which may limit robustness, however, we tried to keep the survey as short and straightforward as possible while seeking relationships between different parameters and characteristics of respondents.

Another limitation is that use of a convenience sampling for the digital survey. This is the main reason why it was important to distinguish between the digital and printed versions of the surveys. There are likely socio-economic differences in the populations questioned via two different means of administration. The printed version was administered in Kfar Saba, whereas since virtual, the digital version could be answered by anyone anywhere in the country. The analog responses were solicited, as cited above, through the use of surveyors who approached passersby. The digital survey was a convenience sample that works as a kind of 'snowball' approach among a particular community (professional, social, intellectual, etc.) of respondents. We sent the link to the questionnaire via e-mail to lists of research centers, and colleagues working in environmental non-governmental organizations, asking them all to share the link with their contacts. We also distributed the link to the questionnaire via social networks (Facebook and WhatsApp groups), asking members to forward the link thus reaching participants beyond the researchers' social and professional circles. We used a convenience sampling approach because it is affordable,

easy and the respondents are readily available (Etikan *et al.* 2016). Internet surveys using this type of convenience sampling have been used to assess perceptions in previous studies (e.g. Loyau & Schmeller 2017).

5. CONCLUSION

Many studies address public perceptions due to the major role of citizens in driving decentralized decision making (i.e., at the household, block or neighborhood level). Even beyond personal-family choices, policy makers will be swayed by public opinion leading to the political will necessary for changing laws and implementing regulation. Moreover, regulatory bodies are needed to engender public trust and assuage worries regarding health risks from reused water, especially household-generated greywater. This study has confirmed the reluctance of the public to take health risks. Since the outbreak of the COVID-19 pandemic, which occurred after the data presented here was collected and analyzed, these concerns are likely to be even greater.

A number of salient take-home messages should inform national policy on domestic water reuse in Israel. First, significant effort must go into informing the public about the three practices studied: reuse of greywater, air conditioner condensate and rainwater harvesting at the household level. The most important factor in decision making by householders regarding willingness to reuse water is that of health risks. Until the public is assured that there are little or no risks to the reuse of water in or near their homes, residents are unlikely to install such systems despite savings on their water bills.

One of the first priorities should include efforts to educate the public about reuse and to dispell inaccurate risk perceptions about certain uses of reused water (i.e., for doing laundry). For the reuse of ACW, younger populations should be targeted and, for household-generated greywater reuse, efforts should target wealthier populations. Lastly, any consciousness raising should involve getting target populations familiar with technologies and practices as well as with the attendant low risks to health if properly managed. Such findings would also provide important input for projects on overall water and wastewater management, even in diverse and distant parts of the world (e.g., Schütze *et al.* 2019).

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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