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Clean enough? Acceptance of urine-derived dry fertilizer and water shaped by religious and social norms in a water-scarce Islamic context

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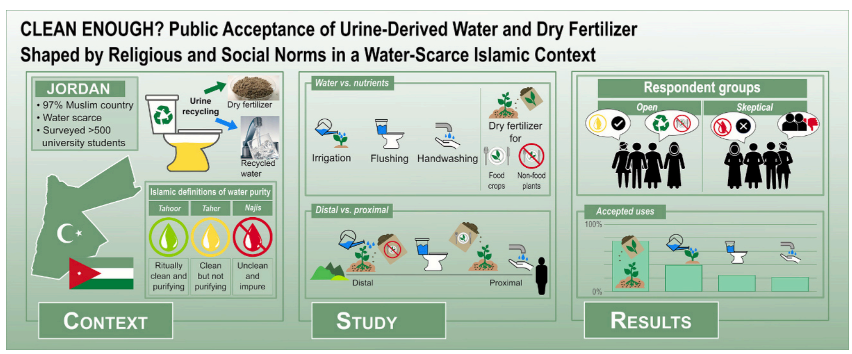
HIGHLIGHTS

- Framing as nutrient vs. water recycling shifts public acceptance of urine
- Islamic purity perceptions (tahoor, taher, najis) are key predictors of public acceptance
- Resistance is driven by disgust and symbolism rather than perceived health risks
- Dry fertilizer is more accepted than urine-derived water, especially for food production
- Family and peer approval drive acceptance more than religious leaders or institutions

GRAPHICAL ABSTRACT



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ABSTRACT

Although wastewater irrigation is broadly accepted in many water-scarce regions, proposals to recycle human urine often face greater social resistance. We hypothesized that this resistance stems because "urine" is perceived as a symbolic substance that triggers stronger cultural and psychological responses than "wastewater." We further predicted that framing urine recycling as nutrient recovery versus water recycling would elicit distinct patterns of acceptance. To test this, we conducted a structured survey in Jordan, evaluating support for four urine recycling scenarios: dry fertilizer, and reclaimed water for handwashing, toilet flushing, or irrigation—each presented in both general and proximal contexts. Support was consistently high for dry fertilizer, particularly when applied to non-food crops, while recycled water for intimate uses such as handwashing received the lowest support. Perception of Islamic jurisprudence regarding cleanliness emerged as central to how respondents evaluated urine-derived water: those who classified it as *taher* (clean but not purifying) or *tahoor* (ritually clean

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and purifying) were generally more supportive, while those who viewed it as *najis* (impure) tended to oppose all forms of recycling. Perceived approval from family and close social circles was a stronger predictor of support than perceived views within the wider religious community, affirming that acceptance is negotiated largely through interpersonal norms in this context. Cluster analysis identified two respondent profiles: a more open group who supported most forms of urine recycling, saw environmental value in the practice, and viewed recycled water as *taher*; and a more skeptical group who were less supportive, particularly in personal or proximate contexts, often viewed the water as *najis*, and anticipated strong social disapproval. Our findings suggest that a starting point for broadening public acceptance of urine recycling could involve engaging agrarian communities, where familiarity with existing wastewater irrigation practices may contribute to greater openness toward resource recovery from human urine. Among the scenarios tested, dry fertilizer derived from urine appears especially promising, as it bypasses many of the cultural and symbolic barriers associated with recycling.

1. Introduction

Human excreta are a valuable biological source of plant-essential macronutrients such as nitrogen, phosphorus, and potassium [1]. For centuries, many societies sustained food production by recycling excreta, thereby effectively closing urban-rural nutrient loops [2]. However, the emergence of centralized sewerage systems in Europe in the mid-19th century introduced a new paradigm. These systems redirected wastewater away from farmlands and into engineered treatment facilities designed primarily to eliminate pathogens and nutrients [3]. This infrastructural shift was accompanied by a cultural one in which human excreta were increasingly viewed not as a resource, but as a contaminant to be diluted and flushed away [4].

Recent advances in source-separated sanitation and decentralized wastewater treatment are beginning to challenge this long-standing paradigm that treats excreta as waste, and they have reopened the possibility of safely recycling it as a resource [5]. It is becoming increasingly feasible to separately collect urine at source within existing urban infrastructure [6], and process it into safe, concentrated fertilizers that can be easily transported and reintegrated into agricultural systems [7]. At a global scale, excreta-derived nutrients have the potential to replace approximately one-quarter of the synthetic nitrogen and phosphorus fertilizers currently used in agriculture [8,9].

The revival of nutrient recycling from human excreta aligns with broader transitions toward circular and climate-resilient food systems, and contributes to several United Nations Sustainable Development Goals (SDGs), including SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Nevertheless, efforts to scale up resource-oriented sanitation systems remain hindered by various challenges [10,11]. Among them, broader social resistance from both communities and institutions to new behaviors and circular practices continues to limit the acceptance and application of new sanitation technologies [12].

Attitudes toward recycling human excreta are shaped by a complex interplay of cognitive and psychological factors, as well as cultural and religious norms. Historically, the association between human excreta and unsanitary practices has contributed to a legacy of distrust that persists in many communities [13]. Longstanding taboos and psychological barriers, particularly the emotion of disgust (or the "yuck factor"), can trigger immediate, visceral rejection of practices involving human excreta, regardless of scientific evidence of supporting their safety or their environmental and human health benefits [14,15]. Religious beliefs can further complicate these attitudes, particularly in cases where religious law, such as Islamic jurisprudence or *fiqh* (فقه) and cultural practices emphasize and shape perceptions of purity and cleanliness [16–18].

These dynamics are particularly salient in the Middle East and North Africa, one of the most water-scarce region in the world [19]. In response to chronic water shortages, many countries in the region have adopted advanced water reuse practices, especially in agriculture. Arab countries, for instance, treat a higher proportion of their urban wastewater (54 %) than do countries in Asia, Latin America and the Caribbean, or sub-Saharan Africa [20]. While Islamic jurisprudence permits the use of treated wastewater in many contexts, including crop irrigation [17,18], the views and behaviors of farmers and the general public do not always reflect the positions of religious scholars or government authorities.

Public acceptance of wastewater recycling in the Middle East and North Africa region varies widely, with reported levels ranging from relatively high [21,22] to very low [23], shaped by context and how the practice is framed. While farmers in the region often use treated municipal wastewater for irrigation, their willingness to do so is largely influenced by practical factors such as water quality, profitability, and perceived social acceptability [24–26]. Among the general public, acceptance of crops irrigated with wastewater tends to be relatively high, although freshwater remains the preferred option when available [24]. In contrast, our previous research revealed markedly negative attitudes among Jordanian university students toward the use of fertilizers derived from human urine on food crops [23]. This divergence is striking given the relative acceptance of mixed wastewater for irrigation, and suggests that "urine," as a label or conceptual category, may trigger stronger psychological and cultural resistance than broader terms like "wastewater."

We hypothesize that "urine" and its constituent components—water and nutrients—may evoke distinct framing cues that elicit different psychological, cultural, and normative responses, helping to explain the difference in public acceptance between mixed wastewater and urine-derived products. To examine these dynamics, this study investigates how university students in Jordan perceive the safe recycling of water and nutrients separately recovered from treated human urine. In contrast to prior research that has examined wastewater recycling as a unified concept, we disaggregate the framing by isolating two specific applications: dry fertilizer derived from urine (nutrient recycling) and water reclaimed from urine for uses such as irrigation, toilet flushing, or handwashing. This approach enables a more granular analysis of factors shaping wider acceptance of resource-oriented sanitation technologies.

The study was guided by the following hypotheses:

(i) Support for urine recycling would be higher for nutrient recycling (e.g., dry fertilizer) than for water recycling applications (e.g., handwashing).
(ii) Cognitive factors, such as perceived environmental benefits and awareness of water scarcity, would positively correlate with acceptance of both applications.
(iii) Psychological barriers would negatively influence acceptance of urine recycling, with a stronger impact on water-focused applications.
(iv) Stricter interpretations of water purity from an Islamic perspective would correlate with lower acceptance, while more permissive views would be associated with higher acceptance.
(v) Perceived social support from family and community would positively influence individual acceptance, whereas perceived disapproval from social circles would correlate with lower acceptance.

By testing these hypotheses within a population of university students from Jordan, we aim to provide actionable insights into the framing effects that shape attitudes toward urine recycling. The findings contribute to broader efforts to advance sustainable sanitation and fertilizer security in water-scarce regions.

2. Methodology

2.1. Study design, participants, and data collection

To our knowledge, urine recycling technologies of the kind explored in this study have not been implemented on university campuses in Jordan. We therefore focused primarily on assessing respondents' behavioral intentions and underlying attitudes using a standardized survey instrument [27]. As in our previous studies of this topic [23,28], the survey instrument was designed to cover three key aspects of Ajzen's theory of planned behavior [29] that can be used to predict intent to perform a behavior, namely, attitudes toward the behavior (Q10, Q12 to Q15), the perceived social pressure to perform or not perform the behavior, or "subjective norms" (Q16 to Q18, Q30), and perceived behavioral controls (Q2, Q3, Q19, Q20). Other questions aimed to determine the level of familiarity with current sanitation practices (Q2, Q3) and current use of treated wastewater in agriculture (Q6), as well as satisfaction with the sanitation status quo (Q4, Q5). Demographics, including respondent level of education, field of study, and family involvement with agriculture, were covered in Q22 to Q29. Respondents were also given the option to provide additional thoughts in an open-ended text response (Q21).

Because respondents were unlikely to have prior direct experience with urine recycling, each scenario included brief descriptions of the relevant treatment processes to ensure that all participants evaluated the same information baseline [27]. Most of the plant-essential nutrients excreted by humans are found in urine and, if its recovery and recycling in agriculture can replace a substantial share of synthetic and mineral fertilizer demand [9]. While the quantity of recoverable water from urine is relatively small, approximately 1.4 L/person/day [30], it can have utility in arid and water-scarce settings. For example, hydroponic systems cultivating leafy greens like lettuce require 0.5 L m^{-2} day^{-1}, meaning that water reclaimed from the urine of one person could irrigate roughly 3 m^2 of crops [31]. Additional contextual information on water and wastewater treatment infrastructure and reuse practices in Jordan is provided in Text S3 of the supplemental material.

We hypothesized that Islamic jurisprudence (theory and philosophy of religious law) regarding cleanliness and acceptable uses of water would be one of the factors determining overall attitudes toward urine recycling. Therefore, we designed the survey to separately evaluate respondent support for safely recycling urine-derived nutrients as crop fertilizer and for water reclaimed from urine (to flush toilets, wash hands, and irrigate food crops). We asked Muslim respondents whether they would categorize water safely reclaimed from human urine as طهور (*tahoor*: pure and purifying, suitable for ablution or purification of objects in Islam), طاهر (*taher*: clean but not purifying), or نجس (*najis*: unclean) (see Table 1 for definitions and examples). Without treatment, water that has had its color, taste, or smell altered by impure substances such as urine is considered *najis* [17,18]. Wastewater that has undergone tertiary treatment to remove solids, pathogens, and salts may be biologically clean ("recycled water"), but is not considered pure under Islamic jurisprudence and is not viewed as suitable for drinking, cooking, ablution (*wudu*), ritual bathing (*ghusl*), or washing clothes. These categories reflect broadly used Sunni classifications of water purity as presented in both contemporary Islamic scholarship on water reuse [17,18] and comparative fiqh works [33].

Recycled water that has been through tertiary treatment is generally considered Islamically acceptable for irrigation, toilet flushing, and other uses where it will not be consumed, although local communities may still find it unacceptable [18,32]. In order to make recycled water pure (*tahoor*) and suitable for ablution and *ghusl*, it must be mixed with large amounts of pure water, although scholars differ on the exact requirements [18,32].

Table 1
Classifications of water purity according to Islamic jurisprudence.[a]

Water classification	Definition	Examples	Uses
Tahoor (طهور)	Pure and purifying	Rain, snow, spring water, groundwater, and water in seas, rivers, lakes, and wells	Allowed for any type of use, but essential for ablution (*wudu*), ritual bathing (*ghusl*)[b]
Taher (طاهر)	Clean from human and animal excreta or *najis* items (such as pork or remains of dead animals) but may contain other impurities that significantly change color, taste, or smell	Water that has been used for ablution (*wudu*), water that has been used for bathing or washing vegetables	Allowed for any type of use other than ablution (*wudu*) and ritual bathing (*ghusl*)
Najis (نجس)	Unclean and impure: water containing any proportion of human excreta (urine or feces), blood, alcohol, or other impure substances that change color, taste, and/or odor	Untreated wastewater, sewerage, human urine	Not suitable any use; if *najis* water touches the human body or items, they must be washed with *taher* or *tahoor* water

[a] Definitions based on Amery & Haddad [17], Tayob et al. [18], and Zahari et al. [32].
[b] Ablution or *wudu* (وضوء) is a practice of ritual purification in Islam where the face, arms, head, and feet are washed in a specific manner with pure (*tahoor*) water. *Ghusl* (غسل) refers to full ablution or ritual bathing, in which the whole body is washed.

While elements of Islamic jurisprudence defining pure (*tahoor*) water and the WHO's drinking water standards overlap in that both require water to be socially acceptable in appearance, odor, and taste, Islamic jurisprudence emphasizes less tangible ritual qualities of water, while the WHO requires scientifically measured health standards be met [18,32,34]. In Muslim societies, any use of treated water must therefore consider the requirements of both schemas (Fig. 1). We designed our survey to address both perceptions of potability and perceptions of purity according to Sunni Islamic jurisprudence.

After review and finalization by all authors, the original English survey instrument was translated into Arabic by D. Alrousan, validated

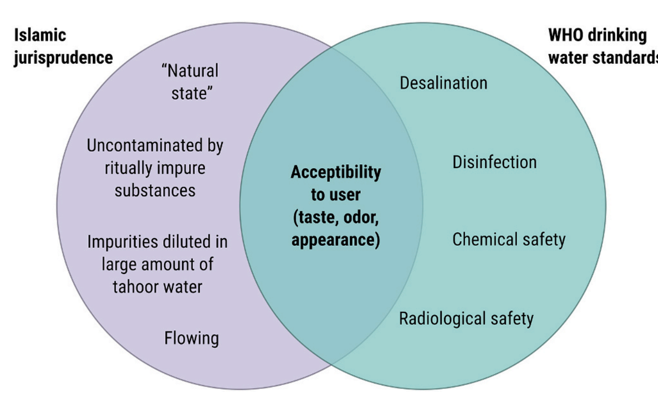

Fig. 1. Comparison of Islamic definition of pure (*tahoor*) water and WHO drinking water standards. Descriptions of the characteristics of *tahoor* water were drawn from Tayob et al. [18] and Zahari et al. [32] and characteristics of potable water from the WHO *Guidelines for drinking-water quality*, 4th edition [34].

by three experts, and translated back to English to verify the accuracy of the translation. The Arabic-language survey was piloted with ten students. Invitations to participate via the online GoogleForms platform (https://www.google.com/forms/about/) were sent to students at 36 universities in Jordan. The survey was left open to collect responses from 7 August 2021 to 11 November 2021 (96 days), with a reminder sent by a researcher on 27 October 2021 (see Fig. S2 in the supplemental material). In total, 26 universities were represented in the responses (see Table S2 in the supplemental material). Because the survey targeted university students, responses reflect stated attitudes and behavioral intentions within a relatively homogeneous population and were elicited using hypothetical scenarios rather than lived experience with urine recycling systems.

Due to the anonymous nature of the survey, ethics approval was not required in Jordan. According to Swedish Statute 2003:460 on the ethical review of research involving humans (https://rkrattsbaser.gov.se/sfst?bet=2003:460), Swedish ethics approval was also not required since participants gave informed consent before completing the survey (Q1) and no uniquely identifying information was collected. Respondents could exit the survey at any time (incomplete responses were not retained). In total, 593 students gave consent and completed the survey, and 18 declined to participate before exiting. The nonresponse numbers for those who exited the survey partway through or who clicked on the link but did not answer any questions are not available due to limitations of the survey platform.

2.2. Data analysis

2.2.1. Data preparation and statistical methods

The majority of survey questions collected binary (yes/no) or five-point Likert-type rating scale responses. Some questions offered categorical options. Age was initially collected as a continuous variable, but since the vast majority of respondents were young university students (mean/median, 22 years), age was not included as a variable in the statistical analysis.

We conducted statistical analyses to evaluate the association between explanatory variables (Q1 to Q6, Q10, Q12, and Q30, all treated as independent variables) and respondent support for safely recycling urine-derived nutrients as crop fertilizer (Q11) and for using water safely extracted from urine to wash hands (Q7), flush toilets (Q8), and irrigate food crops (Q9). First, we assessed for multicollinearity among independent variables using Spearman's rank correlation coefficients and the variance inflation factor. Next, χ^2 tests were applied to determine the significance of association between each independent variable and each dependent variable. For independent variables collected using five-point Likert-type scale question, responses were plotted as the natural log of the odds, ln(*odds*), against the Likert-type scores to examine whether responses showed a linear increase or decrease. Those that did were treated as numeric in subsequent analyses, while variables that did not appear to have a linear response trend were treated as categorical. Independent variables identified by χ^2 tests as $p < .25$ [35] were included in multivariate logistic regression models to isolate their direct effects on each response variable. Due to insufficient sample sizes in some categories, study level and field were excluded from analysis (see Table S3 in the supplemental material). Similarly, non-Muslim respondents, arts students, and PhD-level participants were excluded, resulting in a final dataset of 554 responses used in the regression analyses. All analyses were performed using R [36] with the RStudio development environment [37] and the packages *car* [38], *wiqid* [39], *finalfit* [40], and *lmtest* [41]. Summary statistics were also compiled for variables of interest. To compare overall degrees of acceptance of different scenarios within the respondent group, we used the same cutoffs as those in our previous study [23]: very low (0 to 20 % of respondents found the scenario acceptable), low (21 to 40 %), moderate (41 to 60 %), high (61 to 80 %), and very high (81 to 100 %).

Finally, we used the R packages *klaR* [42,43] and *factoextra* [44] for *k* modes clustering [45], an extension to *k* means clustering adapted for categorical data, to identify different respondent profiles based on responses to Q2–Q20, Q22–Q28, and Q30. The optimal *k* value was selected using the silhouette method [46].

2.2.2. Thematic analysis of open-ended responses

In addition to the categorical variables used in the statistical analysis, we also collected open-ended text responses ($n = 96$) in which respondents could elaborate on their opinions (Q21). We began with a provisional coding framework (Table S4 in the supplemental material) derived from theory, previous work, and our research questions [47]. Deductive codes were assigned to responses following this framework. The framework was then revised as additional themes emerged inductively during the coding process. A single response could be given multiple codes; a few responses could not be coded due to ambiguity and were excluded from the final data set. Three coders (two of whom were Arabic-speaking) first independently coded the English translations of the responses, and then disagreements were resolved by consensus and comparison to the original Arabic responses, with additional input from D. Alrousan and E. Khalid. The final coding framework (see Table S5 in the supplemental material) consisted of 14 thematic codes, which were applied to a final data set of 89 responses (Supplemental File S1). The thematic coding methods are described further in Texts S1 and S2 in the supplemental material.

3. Results

3.1. Demographics and perceptions of sanitation

The results presented below reflect a multi-university student cohort's cognitive attitude toward an emerging sanitation concept. Most respondents were undergraduate students ($n = 522$; 88 %). The remainder of the respondents were master's and PhD students. The typical respondent age (mode) was 21 years (range, 17 to 68 years), and the majority were female ($n = 400$; 67 %). More than half of the respondents ($n = 320$; 54 %) or their close relatives had agricultural work experience. Almost all respondents ($n = 579$; 98 %) were Muslims. Additional demographic statistics are provided in Table S6 in the supplemental material.

Most respondents indicated neutral or low satisfaction with the current sanitation system in Jordan (Fig. 2a). Respondents with access to centralized sanitation in their hometowns ($n = 377$; 64 %) and those who reported using greywater recycling there ($n = 221$; 37 %) were more likely to express satisfaction. Similarly, overall trust in wastewater treatment plants was neutral to low (Fig. 2b); this lack of trust in the sanitation system was also reflected in open-ended responses that expressed concerns about the availability of adequate technology and funding for safe urine recycling in Jordan specifically (File S1 in the supplemental material).

A majority of respondents ($n = 408$; 69 %) correctly indicated that treated wastewater from urban areas is currently used for irrigation in the Jordan Valley, suggesting a relatively high level of awareness of existing wastewater recycling practices, i.e., national figures reporting the use of 170 million cm^3 of treated wastewater for agricultural irrigation in 2020 (for an overview, see Text S3 in the supplemental material).

3.2. Attitudes toward urine recycling

Respondent support for the idea of urine recycling differed greatly by usage type. In both general (Fig. 3a) and proximal (campus; Fig. 3b) cases, respondents preferred dry fertilizer use to water reclamation, although on campus, a majority of students “strongly approved” (44 %) or “approved” (19 %) of recycling water from urine for toilet flushing.

Respondents were more supportive of applying urine-derived dry fertilizer to non-food crops such as landscape or ornamental plants and

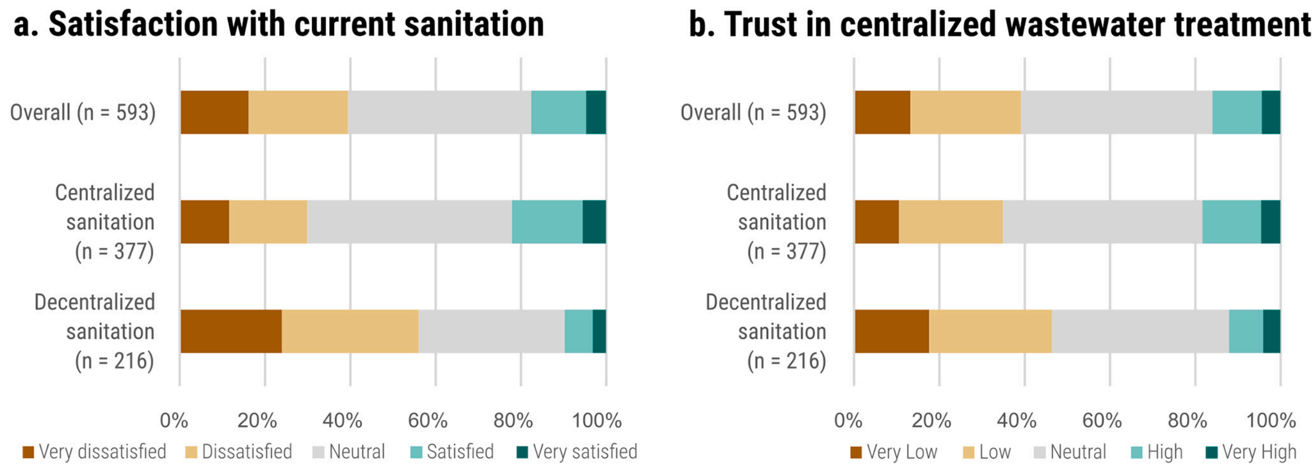

Fig. 2. (a) Satisfaction with current sanitation and (b) trust in centralized wastewater treatment plants, showing both overall satisfaction and trust levels and those among users with centralized and decentralized sanitation. Respondents with centralized sanitation in their hometowns were more likely to express satisfaction with the status quo and trust the effectiveness of water treatment plants.

less accepting of its use in growing edible crops. The type of conditional acceptance of urine recycling based on specific use was elaborated on in 43 % (n = 38) of 89 open-ended responses (Fig. 4a). Examples of suggested uses (primarily for recycled water) included habitat restoration, landscape irrigation or watering of ornamental plants, or unspecified uses that did not involve direct contact with humans or edible food crops. Watering or irrigation of ornamental and inedible plants are the most frequent suggestion, made in some form in approximately 22 % of open-ended responses. Less frequently, respondents mentioned use of dry fertilizer for animal feed crops and recycled water for toilet flushing, facility/household cleaning, industrial use or energy generation, and fire suppression (see Fig. S3 in the supplemental material).

Respondents expressed complex and often mixed views on urine recycling. For example, one respondent stated that “recycling human urine is valuable and acceptable in many areas” but “not psychologically acceptable for direct human use,” including for irrigation of food crops (despite wastewater irrigation being a widespread agricultural practice in Jordan). Others emphasized a need for more research and education about environmental benefits and how the recycling technology works before any recycling projects are implemented (“The idea is almost new and not implemented or widespread, so awareness should be raised about all aspects of this project, especially its drawbacks”). Some made specific suggestions to improve public support, such as starting with watering non-edible plants or providing a video demonstrating the treatment mechanism.

Those who opposed the idea also expressed complex views (“I think it is good for the environment, but not for our health”) and sometimes awareness that subjective disgust coexisted with cognitive knowledge about safety or benefits (“The idea by itself is disgusting, no matter how efficient the treatment process is.”). Others had specific concerns about cost, safety, and feasibility, as well as whether it is necessary to recycle human urine at all.

Within the open-ended responses, conditional acceptance depending on use type was most frequently connected with perceived health risks, conditional acceptance if health and safety standards are met, and perception of negative social norms (Fig. 4b; see File S4 in the supplemental material for full results of Spearman's R test on a smaller subset of n = 30). Perceived health risks were also frequently connected with information seeking (Spearman's $R = 0.4$, $p = .02$, $n = 30$; Fig. 4b). However, perception of negative social norms and perception of health risks were negatively correlated ($R = -0.5$, $p = .005$, $n = 30$).

3.3. Social, religious, and environmental perceptions of urine recycling

Respondents' perceptions of social norms indicated a strong expectation of community disapproval toward urine recycling. A majority (52–55 %) believed that people in their social circles would disapprove or strongly disapprove of such practices, whereas only a small proportion (13–18 %) expected approval or strong approval (see Fig. S4 in the supplemental material).

Religious beliefs were also correlated with attitudes toward urine recycling. Among Muslim respondents, more than half (53 %) categorized treated urine-derived water as *ṭaher* (clean), and thus acceptable for irrigation and cleaning, but not for ablution. Of the remaining respondents, more than twice as many classified water recovered from urine, regardless of whether it is treated to be potable, as *najis* (unclean) (32 %) versus *tahoor* (purifying) (15 %).

Nearly half (49 %) believed urine recycling would have a positive or strongly positive environmental impact (see Fig. S5 in the supplemental material). The majority (77 %) did not think urine recycling would have a negative environmental impact.

3.4. Explaining attitudes toward urine recycling

Through multivariate regression analysis, we identified a number of factors that partially explained level of support for four described use cases for nutrients or water recovered from urine, namely (i) dry fertilizer for crops and use of reclaimed water for (ii) hand washing, (iii) toilet flushing, and (iv) irrigation of food crops (Table 2 and File S5 in the supplemental material).

Perception of the effectiveness of wastewater treatment plants, knowledge of the use of treated wastewater in agriculture in the Jordan Valley, and whether or not the respondent had a family member who worked in agriculture were not significantly explanatory of acceptance. However, the perception of stronger social opposition was co-linear with gender (women perceived stronger opposition). Male respondents were more likely to support use of reclaimed water for irrigation (OR 2.42 [1.56–3.77], $p < .001$).

3.4.1. Cognitive factors

Respondents who perceived urine recycling to be beneficial for the environment showed higher rates of support for both of the more accepted use cases, namely toilet flushing and dry fertilizer use. Notably, a perception that urine recycling would have a beneficial effect on the environment was strongly predictive of support for dry fertilizer use (OR

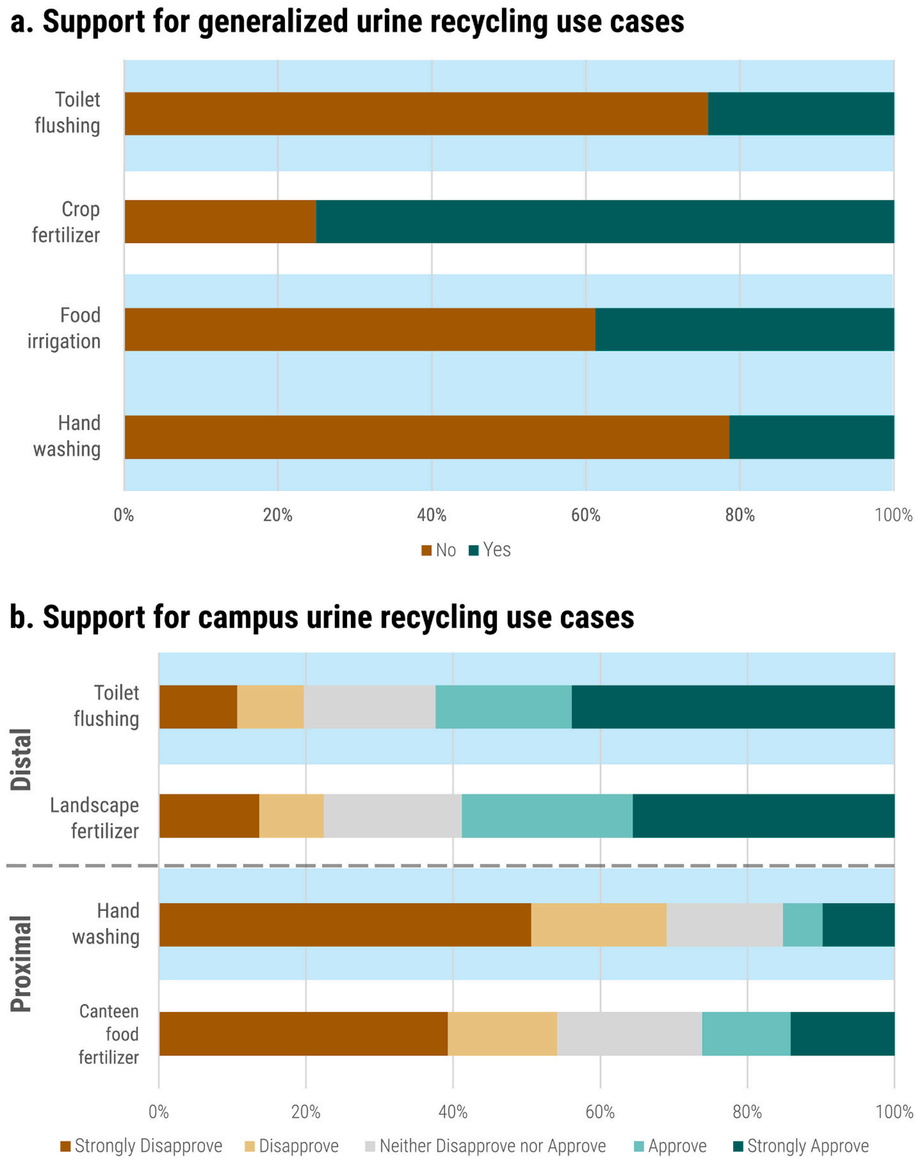

Fig. 3. (a) Support for potential urine recycling use cases. Crops were not specified as being for human food consumption or otherwise. The only use case with a high level of support (75 %) among the respondents was dry crop fertilizer containing nutrients derived from human urine. Cutoffs according to Simha et al. [23]: very low (0 to 20 %), low (21 to 40 %), moderate (41 to 60 %), high (61 to 80 %), and very high (81 to 100 %). Water uses are highlighted in light blue. (b) Stated approval for potential urine recycling use cases in a personal setting (the university campus). When presented with a campus scenario, the more user-distal scenarios of toilet flushing with reclaimed water and use of dry fertilizer on landscaping (not food crops) received more support. The response scale ranged from 1 (strongly disapprove) to 5 (strongly approve). Water uses are highlighted in light blue.

1.95 [1.61–2.39], $p < .001$). Support for installing urine-diverting toilets on campus was also predictive of support for using reclaimed water for toilet flushing (OR 1.27 [1.07–1.51)], $p < .01$), although this effect was smaller.

Perception of urine as containing harmful substances that could pose health risks was generally not predictive of acceptance, except in the case of toilet flushing, where beliefs that urine can contain salts (OR 1.69 [1.05–2.77]) and pathogens (OR 1.73 [1.07–2.81]) were correlated with support for using water reclaimed from urine for flushing ($p < .05$).

3.4.2. Psychological factors

The only variable that was predictive of support across all proposed uses was the perception of water purity according to Islamic law. Respondents who perceived fully treated, potable water reclaimed from urine as *tahoor* were much more likely to support its use for hand washing (OR 21.91 [9.82–53.62], $p < .001$), the strongest effect found in the model, and were also more likely to support irrigation and dry fertilizer uses. Those who perceived it as *taher* were slightly more likely to support both nutrient and water recycling.

Perceptions of social support or disapproval of urine recycling also predicted acceptance of the idea. Besides the belief that recycled water could be considered *tahoor* or *taher*, the perception that family members would support urine recycling was the other main predictor of support for hand washing with recycled water (OR 1.99 (1.61–2.48), $p < .001$). In the case of support for toilet flushing with recycled water, the relationship was less clear, as those who perceived their friends as being neutral about urine recycling (rather than positive or negative) were more likely to support this use. The perceived opinions of friends (OR 2.28 [0.92–5.78], $p < .1$) and family were also weakly correlated with support for use of recycled water for irrigation. However, the relationship between perceived family opinion and support did not show a clear direction. Somewhat surprisingly, given the importance of Islamic perceptions of water purity, perception of the opinions of mosque members was not a significant predictive variable for any of the use cases.

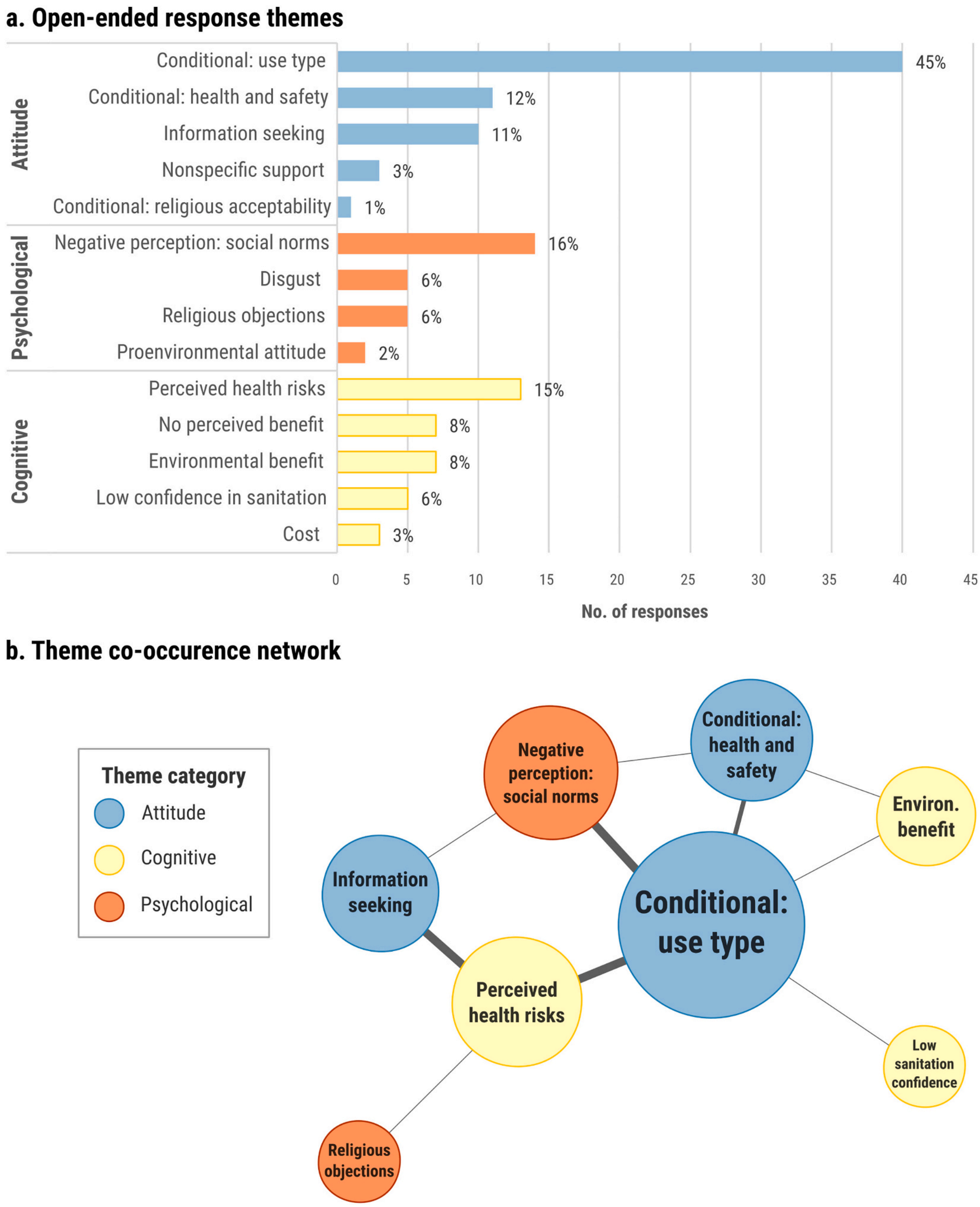

Fig. 4. (a) Themes in open-ended responses. Number of responses coded with each theme, grouped by attitudes and by psychological and cognitive factors affecting acceptance (outlined in [12]). (b) Network diagram showing the most frequently co-occurring themes. Links are weighted by number of connections (cutoff $\geq$2) and circles are scaled proportionally to the log-transformed number of open-ended responses coded for each theme. The most prominent theme was conditional acceptance of some use types but not others, which was most frequently linked to concern about health risk and perception of negative social norms. Concern about health risks was also frequently linked to interest in more information. Both psychological (religious objections and perceptions of negative social norms) and cognitive (concern about health risks, low trust in the sanitation system, and perception of environmental benefit) factors were prominent.

3.4.3. Respondent profiles

Using *k*-modes clustering [45] ($k = 2$, iterations $= 100$), we identified two broad profiles among Muslim respondents (Table 3), corroborating the results of the regression analysis. The first cluster contained “skeptical” respondents ($n = 264$), who typically disapprove of using treated wastewater for irrigation, are less supportive of installing urine-diverting toilets on campus, strongly disapprove of using dry fertilizer derived from urine for either landscape fertilizer on campus or to grow food served on campus, and perceive that their social communities would strongly disapprove of urine recycling. These respondents are less likely to be aware of the current practice in Jordan of using treated wastewater for irrigation, are less likely to have family members working in agriculture, are uncertain whether urine recycling provides an environmental benefit, and consider even treated, purified recycled water to be *najis*.

In contrast, the second cluster contained more “open” respondents ($n = 313$), who are more likely to be aware of and support current wastewater irrigation practices and are more likely to have family members working in agriculture. They are more likely to consider recycled water to be *taher* and to perceive urine recycling as having strong environmental benefits. They strongly approve of installing urine-diverting toilets on campus and using dry fertilizer on campus landscaping but are more neutral about using it to grow food. They also perceive their social communities as being neutral toward the idea of

Table 2
Results of multivariate regression analysis explaining support for selected uses of water and nutrients reclaimed from human urine, including Likelihood ratio test between the full multivariate regression model and the regression model with the selected response variables.[a]

Response variable	OR (95 % CI) predicting support for using water or nutrients reclaimed from urine for			
	Washing hands	Flushing toilets	Irrigation	Dry fertilizer
Current sanitation system				
Greywater source-separation		0.66 (0.41–1.06)+		
Satisfaction with current sanitation system[b]				
Neither dissatisfied nor satisfied		2.04 (1.05–3.93)*		2.01 (1.05–3.83)*
Favor installing urine-diverting toilets on campus		1.27 (1.07–1.51)**		
Perception of water extracted safely from urine				
Taher (clean)	3.05 (1.49–6.93)**	1.77 (1.07–2.94)*	2.20 (1.29–3.81)**	3.56 (2.19–5.83)***
Tahoor (pure)	21.91 (9.82–53.62)***		4.61 (2.26–9.62)***	4.69 (1.99–12.44)**
Perceived opinions of friends on recycling urine on campus[b]				
Neither oppose nor support		2.27 (1.19–4.43)*		
Support			2.28 (0.92–5.78)+	
Perceived opinions of family on recycling urine at home[b]	1.99 (1.61–2.48)***			
Oppose			2.38 (1.18–4.88)*	
Neither oppose nor support			2.56 (1.29–5.18)**	
Support			2.74 (1.14–6.71)*	
Perceived environmental impact of urine recycling[b]		1.56 (1.28–1.92)***	1.61 (1.31–2.00)***	1.95 (1.61–2.39)***
Perceptions of substances present in urine[c]				
Pathogens		1.73 (1.07–2.81)*		
Salts		1.69 (1.05–2.77)*		
Pharmaceuticals	0.54 (0.32–0.89)*			
Gender				
Male			2.57 (1.67–3.97)***	
Likelihood ratio test Pr(>Chisq)	0.2206	0.4366	0.7989	0.4531

[a] For clarity, only response variables found to be significant for at least one outcome variable are shown. In cases where the Likert-type scale results showed a linear trend and were treated as a numeric variable, odds ratios (OR) and 95 % confidence intervals (CI) are shown in the row of the variable name. When the results were treated as categorical, odds ratios are shown for each category compared to the reference category. Significance: +, $p < .1$; *, $p < .05$; **, $p < .01$; ***, $p < .001$; [NS], not significant. For all results, including non-significant results, see File S5 in the supplemental material.

[b] Likert-type scale from (1) strongly dissatisfied/strongly oppose/strongly negative to (5) strongly satisfied/strongly support/strongly positive.

[c] For each substance, the reference category comprised the group who did not think that substance was present. Results were significant only for salts and pathogens.

Table 3
Modes[c] for differing variables between respondent profiles.

Variable[d]	Respondent profile	
	Skeptical (cluster 1)	Open (cluster 2)
WW irrigation awareness	No	Yes
WW irrigation approval	No	Yes
Family in agriculture	No	Yes
UDT on campus	Neither disapprove nor approve	Strongly approve
Landscape fertilizer on campus	Strongly disapprove	Strongly approve
Fertilizer for food on campus	Strongly disapprove	Neither disapprove nor approve
Perception of opinions of…		
Friends	Strongly disapprove	Neither disapprove nor approve
Family	Strongly disapprove	Neither disapprove nor approve
Mosque members	Strongly disapprove	Neither disapprove nor approve
No. of substances in urine	2[a]	0[a]
Perceived environmental benefit of urine recycling	Neither negative nor positive	Strongly positive[b]
Believe purified, recycled water is:	*Najis*	*Taher*

[a] In both groups, the median number of potentially harmful substances believed to be present in human urine was 2.

[b] Median response 4 (positive).

[c] Medians did not differ from the mode for other Likert-type responses.

[d] WW, wastewater; UDT, urine-diverting toilet.

urine recycling.

Despite their broader differences, respondents in both clusters tended to express strong support for the use of recycled water in toilet flushing and generally supported the use of dry fertilizer (although the skeptical group was less supportive of dry fertilizer use in their proximate environment). Both groups strongly opposed the use of recycled water for handwashing.

4. Discussion

Acceptance of urine recycling by respondents in this study was shaped less by cognitive assessments and more by psychological and normative factors. In our previous cross-national survey of university students, attitudes toward urine-derived fertilizer were strongly associated with perceived benefits, perceived legitimacy of urine as a resource, and expectations of peer approval (see Table S3 in [23] for country-specific results). In contrast, the most salient predictors in the present study were religious perceptions of water purity and the perception that one's family or broader community would approve of recycling practices. These findings suggest that in the Jordanian context, support for urine recycling is influenced less by knowledge-based assessments and more by culturally mediated norms, symbolic meanings, and perceived social legitimacy.

4.1. Limited role of risk perception and environmental beliefs

Health concerns are often highlighted as key predictors of public support for sanitation innovations. However, in our study, respondents who believed that urine may contain substances associated with health risks (pharmaceutical residues, hormones, pathogens, or heavy metals), were not significantly more or less likely to oppose its recycling across most applications. This contrasts with prior findings where perceived health risks acted as a cognitive filter for acceptance. Segrè Cohen et al. [48], for instance, found that support for urine-derived fertilizers was contingent on perceived product safety and trust in treatment processes, particularly when used on edible crops. Similarly, Lienert and Larsen [49] found that concerns about micropollutants in urine shaped public attitudes in Switzerland and Germany, where farmers also expressed concern over both safety and legal liability. The weaker role of health risk perception in our study may be attributable, in part, to the way the scenarios were framed in the survey. Unlike our previous study, which focused on recycling urine-derived nutrients for food production applications [23], here we emphasized low-contact applications such as toilet flushing and ornamental landscaping. In addition, the survey included a brief description of the treatment technologies involved, which may have helped establish an implicit baseline of safety in respondents' minds. A similar framing effect was reported by Lienert and Larsen [49], where high levels of acceptance for urine-fertilized vegetables and home gardening were observed when participants assumed that the urine had been safely processed.

Public perceptions of health risks often diverge from expert assessments. For example, while the WHO classifies urine as the least hazardous among domestic wastewater streams in terms of microbial safety and likelihood of disease transmission, a study in Pakistan found that respondents perceived it to be riskier on the basis of its appearance and smell than untreated wastewater, greywater, or even dried feces [50]. Risk, in this sense, is better understood as a culturally encoded construct. Even when not predictive of behavior in statistical models, the importance of perceived health risks should not be underestimated. As others have observed, health risks, whether perceived or actual, can catalyze community mobilization and advocacy [51]. In our study, several participants voiced concerns about health and hygiene in open-ended responses, questioning both the reliability of sanitation infrastructure in Jordan and the institutional capacity to manage wastewater treatment safely. These views matter because they not only reflect latent distrust, but also because individuals who articulate such concerns may be motivated to engage in public discourse or advocacy around sanitation interventions.

Environmental beliefs also had a relatively small influence on the overall attitude toward urine recycling, corroborating findings from our previous survey [23]. While support for the two most accepted use cases—dry fertilizer and toilet flushing—was positively associated with the belief that urine recycling has environmental benefits, perceived environmental benefits were not associated with acceptance of more intimate applications such as handwashing. These findings suggest that pro-environmental attitudes may facilitate acceptance under certain conditions, but their effect is contingent on how the recycled resource is positioned, both materially and symbolically, within everyday social practices. This interpretation is supported by prior research which demonstrated that while biospheric value orientations may contribute to general approval of urine recycling, they lose predictive strength when more affective dimensions, such as perceived risks and benefits, are considered [48]. Hypothetical support of proposed scenarios also does not necessarily translate into willingness to adopt new behaviors [52].

Factual knowledge showed similarly limited explanatory power. Neither awareness that treated wastewater is already used to irrigate crops in Jordan nor familial experience with farming were associated with more favorable attitudes in our regression analysis. However, the cluster analysis using *k*-modes revealed that those with greater familiarity were more likely to express support for using recycled water from urine for irrigation.

4.2. Social norms and religious beliefs are key to acceptance

A majority of Muslim respondents in our study classified treated wastewater as *taher* (clean but not purifying), consistent with the prevailing position among Islamic legal scholars [18]. A minority (15 %) considered it *tahoor* (pure and purifying), which is theoretically possible according to a 1978 Saudi *fatwa* but rarely endorsed in practice as long as more socially and economically acceptable water sources are available [53]. Importantly, nearly one-third viewed it as *najis* (impure), in contrast to official religious rulings. This gap between formal religious jurisprudence and lay perceptions is consistent with findings from other Muslim-majority contexts, where *'urf* (العرف: custom or widely approved cultural practices) may depart from both scholarly interpretation of Islamic law (*fiqh*) and *qānūn* (القانون: written law) in both stricter and more permissive ways [50,54]. While cultural practices in theory only affect the application of Islamic law in limited cases and Islamic law should take precedence in cases of conflict, it is not unusual for *'urf* to be confused with *fiqh* among members of the general public, i.e., for custom to be perceived as religious law, or for individuals to have incorrect or incomplete knowledge of Islamic law [54].

We found that respondents who classified water reclaimed from urine as either *taher* or *tahoor* were generally more supportive of its recycling, including for more intimate uses such as handwashing. Support was strongest when the water was viewed as *tahoor*, suggesting that acceptance is not based solely on perceived safety, but also on symbolic religious purity, which supports our hypothesis that religious perceptions and beliefs, particularly those related to water purity, play a key role in shaping behavioral intent in a Jordanian context. Importantly, however, perceptions of the opinions of members of their mosque communities were not predictive of support for any of the proposed applications. Instead, it was perceived approval from family and close social networks that predicted support, supporting our hypothesis that acceptance is likely to be negotiated through interpersonal norms, rather than determined by institutional doctrine alone.

These dynamics reflect findings from eThekwini Municipality, South Africa, where authorities had proposed a treatment plant for direct potable reuse of municipal wastewater. Initial consultations aimed at anticipating potential objections concluded that there were "no fundamental religious objections" to reuse [55]. Nevertheless, the project soon encountered intense public resistance, particularly from Muslim residents. Although concerns were framed in religious terms, later analyses revealed that rejection was driven less by religious beliefs and more by feelings of disgust, concerns about inequity, and distrust in municipal institutions [56]. In response, officials initiated a dialogue with Islamic scholars and members of the Muslim community, ultimately reaffirming that Islam does not prohibit water reuse, provided that it is carried out safely [18]. By the time consensus was reached the project had already been cancelled. However, in subsequent years, continued severe water shortages have reopened dialogue within the community, and eThekwini now has multiple treatment plants exploring reuse options, including direct potable reuse [57].

Although religious objections to wastewater recycling could be interpreted as stemming from a lack of information or misunderstanding of doctrine, our findings and those from eThekwini suggest that they may also reflect deeper emotional responses, such as disgust, which are subsequently expressed through the language of religion. While informational dialogue about Islamic law, like that conducted in eThekwini [18], may help clarify religious permissibility of recycling practices, such cognitive strategies may not be sufficient if public resistance is shaped primarily by subconscious or subjective disgust [14]. Although disgust can sometimes be softened through education or exposure, it often resists correction through rational argument and can continue to shape judgement beneath the level of conscious awareness [14,15,58].

This lens also helps explain why perceived approval from family and friends was more predictive of support than perceived opinion within religious institutions. When deciding whether a recycling practice is acceptable, people appear to rely more on the social cues of those closest to them. Taken together, these findings suggest that scaling resource-oriented sanitation technologies in culturally sensitive contexts requires more than religious, regulatory or scientific validation. It demands a deeper engagement with the symbolic, emotional and relational dimensions through which communities evaluate what is considered clean and acceptable.

4.3. Acceptance is conditional on sanitation technology and resource end use

Most respondents in our study expressed a sense of either dissatisfaction or neutrality toward the existing sanitation system in Jordan. While satisfaction with the current sanitation system was not predictive of support for urine recycling, these sentiments remain relevant. Studies across diverse cultural contexts (e.g., [59]) have found that users generally prefer sanitation systems that are centrally serviced, especially when such systems minimize direct exposure to excreta, odors, and maintenance tasks, rather than systems that require users to manage excreta themselves. Thus, while current satisfaction levels may not directly drive acceptance, they indicate a baseline expectation for new technologies, such as urine-diverting toilets, to at least meet, and preferably improve upon, the quality of experience under current regimes.

We found that perceptions of sanitation technologies were closely linked to perceptions of their outputs. The most acceptable use case tended to be dry fertilizer applied in contexts removed from direct human contact, although support for recycled water for toilet flushing was also substantial. In contrast, applications such as handwashing and food crop irrigation, which bring the recycled resource into closer physical or symbolic proximity with the body or food system, consistently received lower support. In the open-ended responses, respondents frequently commented on the recycled water scenarios rather than on fertilizer, supporting our hypothesis that water evokes a stronger affective response in this cultural context, likely due to its central role in hygiene and ritual purity. These preferences mirror those found by studies in Türkiye [60] and the United States [48], in which acceptance was higher for indirect use than direct use, particularly when physical or symbolic distance from human ingestion is maintained.

It is also possible that informational context affects attitudes toward specific use cases, at least for some respondents. A large minority of respondents (31 %) were unaware that treated wastewater is already used to irrigate crops in the Jordan Valley, including some grown for human consumption. These individuals were more likely to disapprove of using treated wastewater for irrigation, suggesting that cognitive awareness may also influence acceptance of urine recycling proposals. Although our survey was not explicitly designed to test the effects of information provision, one finding is suggestive: while a majority of respondents opposed the idea of using recycled water for toilet flushing in general, they expressed support for the same practice when it was framed as a university campus initiative. This question was accompanied by a photograph of a urine-diverting toilet, which may have conveyed familiarity, institutional trust, or practical feasibility. The shift in support when more context was provided suggests that affective and psychological barriers, especially around water recycling, can be softened through visual cues and situational anchoring.

4.4. Need for participatory dialogue

The presence of at least two respondent profiles that differed in both background and attitudinal orientation points to a need for diverse, targeted communication strategies. While some individuals may respond to theological or scientific reasoning, others are more likely to be influenced by symbolic cues or interpersonal trust. In such contexts, participatory dialogue could play a particularly important role, not just as a means of disseminating information, but to facilitate community engagement and collective decision-making.

Such dialogue can take multiple forms. In religiously sensitive settings, conversations within faith communities may be especially effective. The experience from eThekwini, South Africa, illustrates how collaboration between local officials and Islamic scholars helped clarify religious permissibility of water reuse [18,56]. However, both our findings and those from eThekwini suggest that religious framing often coexists with affective responses such as disgust or distrust. Participatory processes can create space for communities to question, interpret, and shape how new sanitation technologies are understood and implemented.

Engaging agricultural communities may offer a particularly valuable entry point for broader social acceptance. More than half of our respondents had direct agricultural experience or close family members working in farming. Farmers in Jordan are more likely to have encountered irrigation using treated wastewater and may hold more pragmatic views about the risks and benefits of recycled nutrients [24,25]. A past study from South Africa suggests that participatory action research involving farmers can shift initial skepticism as well as co-produce knowledge and awareness about urine-based fertilizers [61]. Experiences from Uganda likewise demonstrate that co-development and pilot demonstrations with farmers can increase familiarity and legitimacy and encourage uptake of technologies [62]. In addition to and in parallel with consumer acceptance, it is also crucial to understand the concerns of farmers, who were found in a previous study to strongly oppose the use of biosolids due to human and environmental health risks [63]. One key question for future work to explore is whether urine-derived dry fertilizer can be perceptually distinguished from biosolids and demonstrated to adequately address these concerns. Given the high trust often afforded to farmers within their social networks, they may serve as important intermediaries in promoting wider public acceptance, provided they are included meaningfully in shaping how such technologies are introduced and governed.

Nonetheless, creating space for open dialogue can be difficult. In many settings, cultural and religious norms can make it uncomfortable or even inappropriate to discuss topics related to sanitation and human excreta [64]. As a result, practices like wastewater recycling may be widespread but remain unacknowledged and stigmatized in social discourse. Overcoming this silence will require a cultural shift that legitimizes public discourse on these topics.

Who leads such dialogue, and how it is structured, will also be critical [65]. In a context where trust in public institutions remains relatively low and lack of water resources and pollution of drinking water are seen as the most pressing environmental issues by members of the public [66], processes perceived as externally driven or tokenistic may deepen rather than diffuse public skepticism. Dialogues are more likely to gain traction when led by trusted intermediaries, such as local farmers, agricultural cooperatives, and community-based organizations. Involving religious scholars and leaders as co-participants may also facilitate framing of various recycling practices in ways that resonate with prevailing norms.

5. Conclusions

This study investigated the factors shaping acceptance of urine-derived water and nutrients within a multi-university student cohort in Jordan, focusing on specific recycling scenarios. As hypothesized, support was significantly higher for nutrient recycling (dry fertilizer) than for water recycling applications. Cognitive factors such as environmental beliefs, perceived health risks, and factual knowledge were associated with greater support but were not the strongest predictors. Acceptance was most strongly predicted by perceptions of Islamic ritual purity and perceived social support. Notably, perceived approval from family and close social networks had a stronger influence on acceptance than perceived approval from religious leaders and fellow congregants at the mosque.

A key finding is that “urine” is not a singular concept in the respondents' imagination but rather takes on different social and symbolic meanings depending on how it is processed and recycled. Across all contexts, respondents strongly preferred uses that were more physically and psychologically distant from the end user. Use of recycled water for handwashing or to grow food for human consumption were strongly disapproved of. In contrast, when used in contexts physically distant from the body or food system, dry fertilizer derived from urine was widely perceived as acceptable. Urine-derived water, on the other hand, emerged as more socially and symbolically problematic, especially for uses involving bodily contact such as handwashing. Even in Jordan, where treated municipal wastewater is already used in agriculture, the idea of water reclaimed specifically from urine provoked discomfort and scrutiny. These patterns suggest that in contexts similar to Jordan, policymakers aiming to advance circular sanitation could support highvisibility but low-risk pilot projects that focus on recycling urine-derived dry fertilizer for low-contact applications (e.g., university campuses and municipal parks) which are likely to face encounter less resistance.

These insights suggest that scaling up resource-oriented sanitation systems requires a more socially attuned approach to public engagement. Participatory dialogue offers one such mechanism. By creating space for open conversation in trusted settings such as households, agricultural cooperatives, or religious forums, dialogue can help render sanitation technologies less unfamiliar, less taboo, and more embedded in everyday social life. Such engagement can surface latent concerns, correct misperceptions, and cultivate a sense of collective ownership over sanitation transitions.

Finally, urine-derived dry fertilizer appears uniquely positioned to bypass many of the barriers faced by wastewater recycling, particularly in Muslim-majority contexts. It is less symbolically loaded and avoids the ritual complexities associated with water, making it a promising candidate for near-term implementation. Still, our findings suggest that even this application is subject to conditional acceptance dependent on use context, horticultural or agricultural application, and perceived social support. Future research must therefore continue to explore how sanitation technologies and their outputs are framed, discussed, and made socially viable across different cultural landscapes. Longitudinal and mixed method evaluations of pilot projects that introduce urine derived fertilizer or recycled water at scale would help to test whether stated public support translates into actual adoption, and how acceptance evolves as people gain lived experience with urine-derived products.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Prithvi Simha reports financial support was provided by Swedish Research Council. Prithvi Simha reports financial support was provided by Research Council of Norway. Prithvi Simha reports a relationship with Sanitation360 AB that includes: board membership and co-ownership. Sanitation360 AB is a spin-off from the Swedish University of Agricultural Sciences that commercialises technologies for recycling human urine. The authors declare that the work reported in this study was conducted independently and was not influenced by their involvement in the company. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The survey instrument (Arabic-language version administered and an English translation) and raw data are deposited at Mendeley Data under DOI 10.17632/3n752w8g6x.1 [27]. R code for the statistical analyses is available in Files S2 and S3 in the supplemental material. Original, translated, and coded open-ended responses, a detailed description of thematic coding methods, and the provisional and final coding frameworks are available in File S1, Texts S1 and S2, and Tables S3 and S4 in the supplemental material.

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