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# The importance of user acceptance, support, and behaviour change for the implementation of decentralized water technologies

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Decentralized water treatment technologies could help in addressing global key water issues. Their successful implementation, however, depends on users' positive valuation and, depending on the technology, 'passive' use (rooted in acceptance), 'engaged' use (rooted in support) or 'active' use (rooted in behaviour change). Although users' valuation of a technology is contingent on its characteristics, positive valuation and use usually also require supporting promotion activities. Here we review the literature on psychological determinants of use as well as change techniques to promote use, and propose a user-focused theory of change to guide promotions. Our review highlights a lack of (conclusive) evidence on both psychological determinants and effective change techniques. We call on environmental and health psychologists to intensify their research on 'passive', 'engaged' and 'active' use of decentralized water treatment technologies and encourage engineers, practitioners and psychologists to intensify collaboration to ensure that technologies, implementation and promotions are optimally integrated.

Fresh water in sufficient quantity and quality is a basic requirement for human health and well-being[1,2]. Yet, in 2020, 26% of the world's population, primarily residing in low- and middle-income countries (LMICs), did not have access to potable water[1]. In addition, fresh water is an increasingly scarce resource, pressured by climate change, rapid urbanization and population growth[2]. Decentralized water treatment technologies (henceforth called decentralized treatment technologies), such as household-based chlorination[3,4] or wastewater recycling[5], could alleviate these issues. However, these technologies can only be successfully implemented if users accept them[6,7], that is, if users receive the technologies with approval[8], and use them 'passively' (see Box 1 for examples of 'passive' use). For example, several potable wastewater reuse projects had to be cancelled because of public opposition[9,10], rooted in health concerns or in a feeling of disgust at the idea of drinking former wastewater.

Moreover, the use of decentralized treatment technologies may even call for support, that is, agency for and engagement with the technologies[8], required for 'engaged' use, or a change in behaviours and routines[11], required for 'active' use (see Box 1 for examples of 'engaged' and 'active' use). This may present a major barrier to a successful implementation of decentralized treatment technologies. For example, according to a study on the promotion of chlorine use in Bangladesh, required behaviour change may explain the generally low use of household-based water treatment (for example, refs. [3,12–14]). Specifically, after promotion ceased, household-based chlorination, which requires new routines (Box 1), dropped by over

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50%. In contrast, the use of a passive chlorinator, installed at existing, shared hand pumps whose use does not require any new routine, did not decrease[4].

Engineers and practitioners increasingly acknowledge that acceptance, support and behaviour change (1) are key for a successful implementation of decentralized treatment technologies, and (2) although dependent on the characteristics of the technologies, have to be actively promoted[4,15]. However, they may be insufficiently aware of the variety of factors motivating or hindering people to use the technologies and may thus lack knowledge on how to promote use effectively. For example, product costs[3] and low awareness of the health risks of drinking untreated water[3,16] are often considered the main barriers to household-based water treatment. However, research shows that the use of such technologies remains low even when the required products and intensive health promotion are provided, which indicates that additional factors are equally or maybe even more important for a behaviour change[3,12,17].

In psychology, it is widely accepted that for promotions to be most effective, they should be based on theory and evidence on how change happens[11,18]. Specifically, they should build on two types of information: (1) information on the determinants of use, that is, drivers of and barriers to acceptance, support and behaviour change, and (2) information on the specific change techniques that are expected to increase use by changing the determinants (change techniques are the active ingredients of a promotion strategy that bring about change[18]). Following inter- and transdisciplinary research, we refer to such information as a theory of change (ToC), a comprehensive description of how and why change can be expected to be achieved[19,20] (see also ref. [21]). The 'how' represents the specific change techniques or activities of a change initiative, and the 'why' represents the determinants or outcomes that build the causal link between the activities and the aspired change or impact.

Environmental and health psychologists have in-depth knowledge about the determinants of acceptance, support and behaviour change and about techniques to promote them (see ref. [22]). However, they tend to focus on topics other than the use of decentralized treatment technologies (see ref. [22]). As an exception, the Risks, Attitudes, Norms, Abilities and Self-Regulation (RANAS) model[11] (Fig. 1) can be understood as a user-focused ToC specifically developed for the water, sanitation and hygiene (WaSH) sector in LMICs. The model is based on theories and evidence from social and particularly health psychology and presents five types of determinants of behaviour change (that is, outcomes) and related change techniques (that is, activities): (1) perceived health risks, for example, of consuming non-purified water; (2) attitudes towards purification, such as perceived costs and benefits of purification and affective reactions; (3) social and personal norms sanctioning or supporting a given behaviour; (4) perceived ability to use a technology, such as believing to have the necessary means; and (5) self-regulation, such as planning the use and coping with barriers. A revised version of the RANAS model[23] also considers the contextual factors in which the behaviour and its psychological determinants are embedded.

Although the RANAS model[11] constitutes an excellent starting point for a comprehensive, user-focused ToC for acceptance, support and behaviour change related to decentralized treatment technologies, it has two shortcomings. First, a substantial part of the underlying evidence stems from research on health behaviour change (rather than technology use) in high-income countries, as corresponding research in the WaSH sector was limited. This implies that determinants and change techniques that are specific (1) to the WaSH sector in LMICs and (2) to technology use might be missing. Second, and related to (2), the model does not consider acceptance and support, which might (partly) have different determinants than behaviour change or for which certain determinants might be more/less important.

## Overview of the present review

To address the above shortcomings, we review the literature on the psychological determinants of acceptance, support and behaviour change related to decentralized treatment technologies and on change techniques aimed at promoting the technologies. We report our findings structured according to the RANAS factors[11]. Identified determinants extending or going beyond the RANAS factors will be introduced as additional determinants. On the basis of our findings, we propose a user-focused ToC to help guide the promotion of decentralized treatment technologies.

Our review focuses on two groups of decentralized treatment technologies that are expected to cover the range from 'passive' to 'active' use (Box 1). First, decentralized drinking water purification technologies[3,4,12] (henceforth called purification technologies) that treat water for potable use and are primarily applied in low-resource settings in LMICs[1]. These technologies are usually assumed to require 'active' use through a change in behaviour and routines[4,11]. Second, decentralized wastewater treatment systems with reuse[15,24] (henceforth called reuse systems) that collect and treat wastewater near its source of generation, where the water is also reused[24,25]. Reuse systems are increasingly used in booming megacities in LMICs[26,27]. They can be implemented at household, cluster and neighbourhood scales (Box 2) and usually require 'passive' use through acceptance[6,7] or 'engaged' use through support but rarely 'active' use.

For purification technologies, our review focuses on experimental and correlational studies that varied potential determinants systematically or correlated them with use, respectively (Table 1). All but one of the reviewed studies was conducted in LMICs, where purification technologies are primarily implemented[1]. For reuse systems, experimental and correlative evidence on determinants is limited. Therefore, we additionally consider descriptive and qualitative studies that asked respondents directly about the importance of determinants (Table 2). However, these findings will be treated as initial evidence only, as research indicates that people tend not to recognize the causes of their behaviour and decisions[28,29]. While reuse systems are increasingly used in LMICs[26,27], it is noteworthy that of the reviewed studies on the determinants of use, only a third stem from LMICs. For both groups of technologies, our review on change techniques to increase use will focus on experimental studies only.

## RANAS-related determinants of use

### Risk factors

In consistency with the RANAS model[11], several studies have indicated perceived health risks that could be reduced by using purification technologies as a driver of use (see also ref. [16]). Specifically, people were more likely to use a purification technology, the better their health knowledge[30–34], the more they believed their drinking water to be unsafe[34,35], felt at risk of contracting a water-borne illness[36,37], thought this would be severe[36,38], and were concerned about it[31].

Similarly, relevant drivers of the use of reuse systems seem to be perceived environmental risks that could be reduced by use, such as environmental pollution and water scarcity[39,40]. An experimental study showed that when people had been confronted with environmental risks, they were more likely to find reuse systems acceptable[40]. Moreover, people were more likely to find reuse systems acceptable if they had experienced water shortages[39], a proxy of water scarcity.

Extending the RANAS model[11], research on reuse systems suggests perceived risks resulting from using such systems as barriers to use. Specifically, perceived health risks have been indicated by potential users as barriers to use[39,41] and have been found to be associated with lower acceptance[42] and willingness to invest resources[43]. Moreover, people found the systems less acceptable when they perceived a higher general risk from using these systems[44] as well as when they had experience with the technology working unreliably[42], a proxy of risk of system failures.

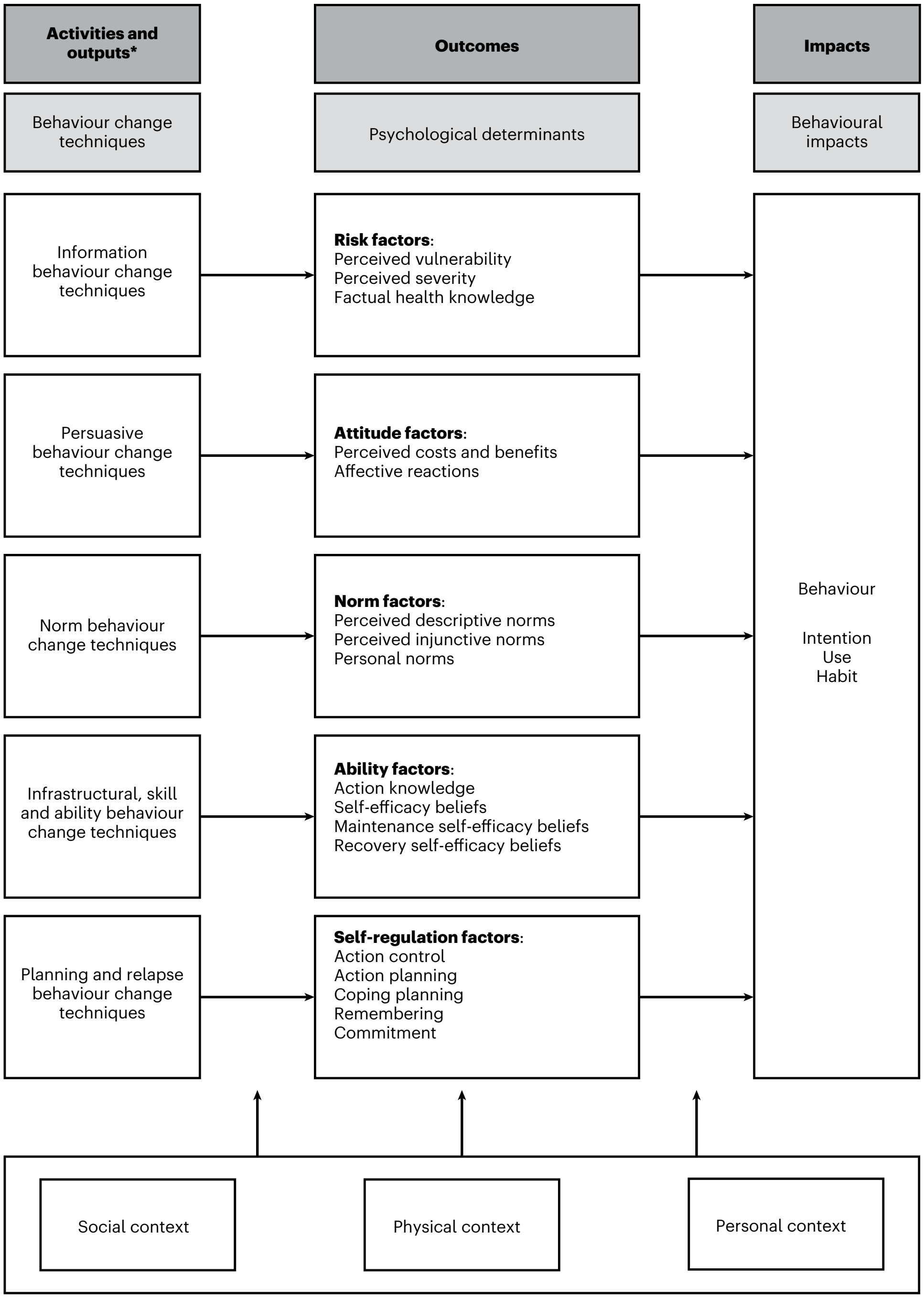


**Fig. 1 | The RANAS model.** *In the present context, outputs represent different promotions that are made up by (1) their content and (2) their delivery channels. The content is defined by the applied behaviour change technique(s), such as providing personal risk information and prompting public commitment. These may be brought to the users through different (communication) channels, such as posters, community meetings or household visits. Figure adapted with permission from ref. [11], Taylor & Francis, and ref. [23], Eawag.

## Attitude factors

Most of the reviewed studies on purification technologies indicate perceived costs and benefits as determinants of use. However, the specific types of perceived cost and benefit found to be associated with use varied greatly between studies, with one exception: in many studies, a perceived bad (or good) taste of the purified water was found to be associated with lower (or higher) use[17,30,33,36,37,45,46] and technology maintenance[47]. Other perceived costs found in some studies to be associated with use[17,30,33,47,48] included the distance of the shared purification technology[30], effort[48] and monetary costs[17,33,47] (see also refs. [49,50]). As to perceived benefits, monetary savings[36] and health benefits[38,46,47,50] related to using the technology as well as the technology's large water capacity[47,50] were found to be associated with higher willingness to pay for[50] as well as use[36,38,47] and maintenance[47] of the technology, respectively.

Also for reuse systems, perceived costs and benefits have been indicated as determinants of acceptance[39,41,51]. Perceived costs that were mentioned by study participants as barriers to acceptance are odours released from the systems[39,41] and poor water quality[39,41]. Relatedly, odours and a reduced water quality were found to reduce people's willingness to invest in a reuse system[51], suggesting reduced support. Monetary costs of installation and of operation, monitoring and maintenance (OMM)[39,41] as well as a burden on the homeowner through OMM[39] were also mentioned by study participants as perceived

## BOX 1

# Description of the considered decentralized treatment technologies and required type of use

**Purification technologies.** Particularly in low-resource settings in LMICs, people may lack access to safe drinking water[1]. Their water sources may, for example, be contaminated by pathogens, often of faecal origin, causing diarrhoea[4], or by natural, geogenic contaminants, such as fluoride, causing fluorosis[87]. Purification technologies can be used to remove these contaminants, thus providing access to safe drinking water[4,87]. The technologies can be household based, shared by multiple households or community based (that is, shared by a community). In this Perspective, we review studies investigating the use of various purification technologies. These include household-based solar water disinfection (SODIS: see image on top; credit: Silvia Palacio)[36,59], household-based chlorination[33], community-based ultrafiltration[48] (for the technology, see ref. [88]), and household-based[45] and community-based[17,30] fluoride filters.

**Required type of use for purification technologies.** While the minimal requirement for the successful implementation of purification technologies is 'passive' use, in most cases, 'engaged' use or even 'active' use, based on a change in behaviour and routines[4,11], will be required. Whether a specific technology requires 'passive' versus 'engaged' use, or 'engaged' versus 'active' use might not always be clear cut and might depend not only on the implementation approach but also on previous routines and perceptions of users. Below we provide examples of technologies and implementation settings requiring 'passive', 'engaged' and 'active' use.

- 'Passive' use, rooted in acceptance: use of passive chlorinators, installed at previously used, shared hand pumps (that is, no change of routines required)[4] and without users having to contribute monetarily or otherwise to the installation and use.
- 'Engaged' use, rooted in support: use of passive chlorinators, installed at previously used, shared hand pumps (that is, no change of routines required)[4] with users contributing, for example, monetarily to installation, monitoring and maintenance.
- 'Active' use, rooted in behaviour change: household-based chlorination, which requires the acquisition of the following new routine:
  - If none at home, buy chlorine.
  - If water is turbid, filter it through a cloth.
  - Take the right amount of chlorine required for the volume of water to be treated.
  - Add chlorine to water.
  - Mix the water well, using a clear utensil.
  - If a cover is used to protect the water, replace it.
  - Wait until water is disinfected (30 minutes).

**Reuse systems.** Reuse systems are sanitation solutions that collect and treat wastewater near its point of generation for potable or non-potable on-site reuse (see image at bottom; credit: Josianne Kollmann)[24,25,89]. Thus, the systems offer a mean for both wastewater treatment and saving of freshwater resources[90,91]. Both greywater (that is, wastewater from sinks, showers, washing machines or dishwashers) and blackwater (that is, wastewater from toilets) can be treated, either separately or jointly[15]. The treated water can be reused, for example, for irrigation, cleaning, toilet flushing or even potable purposes. If the wastewater is not treated up to potable quality, a dual piping system needs to be installed for all indoor reuse purposes (that is, separate piping systems for fresh and treated water that prevent mixing of the two water streams)[92]. The most commonly used treatment technologies are sequencing batch reactors, membrane bioreactors, moving bed biofilm reactors and activated sludge process[93].

Reuse systems are an alternative to centralized reuse systems, which serve, for example, an entire city (for example, refs. [52,94]). For centralized systems, a sewer network is necessary that collects the wastewater, which is treated centrally and fed back into the centralized water system, for example, through dual piping systems (called 'purple pipes') or through recharge of the drinking water source. Reuse systems do not depend on a sewer network and therefore present a particularly attractive and flexible solution for settings without, with limited or with ageing centralized (waste)water infrastructure and varying population sizes[15,27]. They are therefore increasingly applied in booming megacities of LMICs that usually lack comprehensive, centralized wastewater treatment infrastructure and increasingly face water scarcity[26,95].

**Required type of use for reuse systems.** For the implementation of reuse systems to be successful, 'passive' or 'engaged' use will mostly be sufficient. However, in some cases, 'active' use may be necessary. Examples of 'passive', 'engaged' and 'active' use are provided below:

- 'Passive' use, rooted in acceptance: being in favour of the system (for example, at a communal assembly), and use of the treated wastewater.
- 'Engaged' use, rooted in support: users investing resources, such as time and money, into organization of the installation, operation, monitoring and maintenance.
- 'Active' use, rooted in behaviour change: users are responsible for operation, monitoring and maintenance and have to regularly check the quality of the treated water or replace broken parts of the system.

**BOX 2**

# Characteristics of wastewater reuse systems at different implementation scales and determinants of use

Wastewater reuse systems can be implemented at different scales[44,69], ranging from household scale (that is, single household), via cluster scale (that is, multiple households), to neighbourhood scale (that is, several hundred households). The scale of the system has different implications for the users and might thus influence acceptance. For example, at the household scale, the systems are usually owned by the household, while with increasing scale, they are usually owned by an increasing number of households or even the utility[15,96]. This may affect the users' responsibility for OMM. Users of systems at the household and cluster scales may be responsible for OMM and might be concerned about this responsibility. This has been reported as a barrier to accepting wastewater reuse systems[25,39]. Relatedly, these users may be more concerned about health risks and the water quality, as the treated wastewater is usually not controlled by a utility[96].

Yet, at the same time, systems at household-scale collect wastewater generated by fewer persons who are more familiar with each other compared with larger-scale systems. The treated wastewater may therefore evoke less disgust and may thus be perceived as more acceptable. Indeed, in a study in the United Kingdom, residents showed higher willingness to use treated wastewater collected at their own households than wastewater from public buildings or neighbouring households[56].

As systems at different scales require different amounts of personal engagement, different types of use may be necessary. While 'passive' use may be sufficient for larger-scale systems with less personal involvement, smaller-scale systems may require 'engaged' use, for example, when allocating time or money to support OMM. For residents responsible for OMM of the systems, 'active' use is necessary.

To induce the 'engaged' and 'active' use potentially necessary for smaller-scale systems, psychological ownership (Box 3) might be an important driver. Specifically, it can be assumed that stronger feelings of individual ownership is needed for household-scale systems to be well working, whereas for systems at the cluster scale stronger feelings of collective ownership may be needed. At the neighbourhood scale, at which the ownership and especially the OMM of systems is often externalized, psychological ownership is most likely not needed for a well-functioning system.

**Simplified assumptions about characteristics and determinants at different implementation scales**

| Characteristics and determinants | Household scale | Cluster scale | Neighbourhood scale |
|---|---|---|---|
| Coverage | Single household | Multiple households | Several hundred households |
| OMM | Homeowner | Shared (multiple homeowners) or externalized (company) | Externalized (company or utility) |
| Perceived health risks | Higher | Higher | Lower, as water quality is controlled externally |
| Level of disgust | Lower, as co-users are few and familiar | Lower, as co-users are fewer and more familiar | Higher, as co-users are many and less familiar |
| Required type of use | 'Engaged' use or 'active' use | 'Passive' use or 'engaged' use | 'Passive' use |
| Facilitator of system sustainability | Individual psychological ownership | Collective psychological ownership | No psychological ownership needed |

barriers. Perceived benefits of reusing treated water mentioned by study participants as drivers for accepting reuse systems were monetary savings[39,41] and environmental benefits[41].

Affective attitudes about purification technologies were researched in only five of the reviewed studies[17,35–37,45] and in only one of them were they found to be associated with use. Specifically, feeling proud about serving purified water to guests was found to be associated with higher use[45].

The good feeling about conserving water through reuse systems was mentioned as a driver of acceptance in one study[41]. Moreover, regarding the reuse of treated wastewater in general, research indicates that feelings of disgust are an important barrier to acceptance, commonly known as the 'yuck' factor[52–55]. Probably because of this 'yuck' factor, people find the reuse of treated wastewater more acceptable, the lower the physical contact with the reused water[43,51,56–58]. Specifically, using treated wastewater for irrigation or toilet flushing is more accepted than using it for laundry washing, while potable reuse is least accepted.

## Norm factors

Several studies indicate social norms as determinants of the use of purification technologies. The higher the perceived number of people using a purification technology, the more likely people were to use[33,36,47,48,59] and maintain[47] the technology. In addition, people were all the more likely to use purification technologies, the more they assumed that important others would appreciate it[32,33,48].

To our knowledge, the role of social norms has only been explored with regard to the acceptance of centralized reuse technologies (for example, refs. [52,60–62]). For example, one study showed that the more residents thought that others would support a centralized reuse project, the more they found it acceptable[52].

Personal norms to use purification technologies were considered in only three of the studies reviewed[17,30,33]. In only one of these studies was a stronger feeling of moral obligation found to be associated with higher use[33].

For reuse systems, personal norms have been found to predict support[5]. Specifically, the more a household felt morally obliged to reduce the amount of untreated wastewater discharged into the environment, the higher were their intentions to install them.

## Ability factors

Ability factors are only expected to become relevant when a successful implementation of decentralized treatment technologies requires 'engaged' use and especially when it requires 'active' use (Box 1). In several studies on the use of purification technologies, ability factors were found to be associated with use. These included knowledge about purification technologies[34] and about how to use them[33,38], perceived availability of the required material[36], not experiencing technical

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**Table 1 | Overview of reviewed studies on determinants of the use of purification technologies**

| Study | Considered determinants | Technology | Study design | Country |
|---|---|---|---|---|
| Ref. [59] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors | HB SODIS | Correlational | LMIC |
| Ref. [49] | Risk factors<br>Attitude factors<br>Contextual factors | HB chlorination | Experimental and correlational | LMIC |
| Ref. [50] | Attitude factors<br>Contextual factors | HB gravity-driven membrane filter | Experimental | LMIC |
| Ref. [48] | Attitude factors<br>Norm factors<br>Ability factors<br>Self-regulation factors<br>Psychological ownership | CB ultrafiltration | Correlational | LMIC |
| Ref. [31] | Risk factors<br>Contextual factors | HB lead filter | Correlational | HIC |
| Ref. [38] | Risk factors<br>Attitude factors<br>Norm factors[a]<br>Ability factors<br>Contextual factors | HB treatment technologies | Correlational | LMIC |
| Ref. [37] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors<br>Self-regulation factors | HB treatment technologies | Correlational | LMIC |
| Ref. [32] | Risk factors<br>Norm factors | HB SODIS | Correlational | LMIC |
| Ref. [36] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors | HB SODIS | Correlational | LMIC |
| Ref. [45] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors<br>Self-regulation factors<br>Habit | HB fluoride filter | Correlational | LMIC |
| Ref. [17] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors<br>Self-regulation factors | CB fluoride filter | Correlational | LMIC |
| Ref. [30] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors<br>Self-regulation factors<br>Habit | CB fluoride filter | Correlational | LMIC |
| Ref. [35] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors[a]<br>Self-persuasion | HB SODIS | Correlational | LMIC |
| Ref. [33] | Risk factors<br>Attitude factors<br>Norm factors<br>Ability factors<br>Social discourse | HB chlorination | Experimental | LMIC |

**Table 1 (continued) | Overview of reviewed studies on determinants of the use of purification technologies**

| Study | Considered determinants | Technology | Study design | Country |
|---|---|---|---|---|
| Ref. [46] | Attitude factors<br>Technological effectiveness<br>Community capacity<br>Inherent demand | HB dual-media, gravity-fed filter | Correlational | LMIC |
| Ref. [34] | Risk factors<br>Ability factors<br>Habit<br>Contextual factors | HB treatment technologies | Correlational | LMIC |
| Ref. [47] | Risk factors<br>Attitude factors<br>Norm factors<br>Self-regulation factors | HB arsenic sand filter | Correlational | LMIC |

[a]Due to measurement issues, including issues with operationalization, the determinant is not reported in the main text. CB, community based; HB, household based; HIC, high-income country; LMIC, low-income country.

problems[34], feeling that the use fits into one's daily routines[36], feeling able to prepare sufficient purified water[17,45], as well as being confident to use the purification technology regularly[33,48], even in light of barriers[33,48], and to recover from relapse[33,37,48].

For reuse systems, a lack of experience in OMM has been indicated by homeowners as a barrier to implementation while availability of funds was mentioned as a driver[39]. Moreover, detailed knowledge about the functioning of the system has been mentioned by users as a driver for acceptance[63].

### Self-regulation factors

Self-regulation factors are expected to become relevant when a successful implementation of decentralized treatment technologies requires 'active' use (Box 1). Only five of the reviewed studies on purification technologies tested self-regulation factors as drivers of use[17,30,37,45,48]. One[45] of the studies found no associations and two[17,48] found only higher commitment to be associated with higher use. The remaining two studies[37] found, in addition to commitment, better action control[37], better plans on what to do in case of barriers[37] and better remembering[30,37] to be associated with use. We are not aware of any research on self-regulation factors related to the use of reuse systems.

## Determinants of use beyond the RANAS factors

While the majority of the reviewed determinants of acceptance, support and behaviour change related to decentralized treatment technologies are in line with the RANAS factors[11], three key determinants that emerged from the literature go beyond them. These are discussed below.

### Perceived fairness

For reuse systems, a perceived fair distribution of the costs, risks and benefits of the systems among different groups of society (that is, distributive fairness[64]) has been found to be associated with higher acceptance for systems at the cluster scale (but not at the neighbourhood scale)[44]. In research on centralized reuse systems[62,65] and other technologies (for example, refs. [66,67]) both perceived distributive fairness[62,66,67] and perceived fairness of the decision-making process[65,66] (that is, procedural fairness[64]) have been found to be associated with increased acceptance.

### Trust in water authorities

For reuse systems at the neighbourhood scale but not at the cluster scale[44] as well as for centralized reuse systems[65], research has shown that higher levels of trust in water authorities were related to increased

**Table 2 | Overview of reviewed studies on determinants of the use of reuse systems**

| Study | Considered determinants | Study design | Country |
|---|---|---|---|
| Ref. [51] | Attitude factors | Experimental | LMIC |
| Ref. [57] | Attitude factors | Descriptive | HIC |
| Ref. [42] | Attitude factors | Correlational | HIC |
| Ref. [40] | Risk factors | Experimental | HIC |
| Ref. [56] | Attitude factors | Correlational | HIC |
| Ref. [41] | Risk factors<br>Attitude factors | Qualitative | HIC |
| Ref. [44] | Risk factors<br>Perceived fairness<br>Trust | Correlational | HIC |
| Ref. [5] | Norm factors | Correlational | LMIC |
| Ref. [43] | Risk factors<br>Attitude factors<br>Ability factors[a] | Correlational | HIC |
| Ref. [39] | Risk factors<br>Attitude factors<br>Ability factors | Qualitative and correlational | LMIC |
| Ref. [63] | Ability factors | Correlational | LMIC |

[a]Due to measurement issues, including issues with operationalization, the determinant is not reported in the main text. HIC, high-income country; LMIC, low-income country.

acceptance. For 'passive', 'engaged' and 'active' use of decentralized treatment technologies, trust in operators, in OMM and the technology itself could also be relevant. Research on other technologies (for example, ref. [66]) found trust in implementing actors and the technology indeed to be associated with increased acceptance.

### Psychological ownership

A study on community-based purification technologies suggests collective psychological ownership as an additional driver of use[48] (Box 3). That is, the more people felt the technology to be 'theirs', the more likely they were to use it. Importantly, this study and research on community-based piped water supply[68] suggest that psychological ownership might help in motivating people to engage in individually costly behaviour that ensures the technology's sustainability (Box 3). In line with these findings, scholars have suggested that psychological ownership may influence the functioning of reuse systems[39,69,70]. However, this has not yet been tested.

## Evidence on change techniques to promote use

To increase the use of decentralized treatment technologies, promotions have to be designed that aim to strengthen the relevant drivers or reduce the indicated barriers, respectively. To this end, evidence is needed on the effectiveness of promotions and specifically on the effectiveness of the change techniques that target these drivers and barriers[18].

To our knowledge, only one study[40] tested a promotion aimed at increasing the acceptance of reuse systems (for studies testing promotions to increase the acceptance of the reuse of treated wastewater in general, see for example, ref. [71]). The study showed that priming environmental risk perception increased study participants' acceptance, even when disadvantages of the systems were presented, which indicates that risk techniques[23] can help promote decentralized wastewater reuse.

Various studies that aimed at increasing the use of purification technologies 'provided health information' (for example, refs. [33,72]), often in combination with 'providing material' (for example, refs. [3,12,13,73]). According to the RANAS model[23], these measures are risk and ability techniques, respectively. Other change techniques, however, have been applied much less frequently. Below we discuss some promotion studies that did so, sorted according to the type of determinant they targeted and referring to the 'change techniques' of the RANAS model[23]. It is noteworthy that most of these studies applied multiple change techniques, making it difficult to assess the effectiveness of each technique separately.

A trial in India applied the risk technique 'personalized risk information' to increase the use of purification technologies[74]. Use was lower in households receiving only information on safe water management than in households additionally receiving personalized risk information.

Several studies applied cost–benefit techniques to increase use, such as '(re-)assessing the costs and benefits' of purification technologies[17,33,72]. The techniques were found to reduce perceived costs of the technologies (without changing actual costs)[17,72] while increasing the perceived benefits[33,72] and use[17,72].

Two social norm techniques were used in a study on chlorine use in Chad[33]. 'Informing about others' behaviour' and 'prompting public commitment' resulted in increased chlorine use, mediated by an increase in perceived descriptive norms (see also refs. [13,72]).

The same study applied ability techniques, namely 'providing detailed instructions' on how to correctly use chlorine and 'demonstrating its correct use'[33] (see also refs. [72,75]). This increased chlorine use by enhancing people's knowledge on correct use and making them feel able to use the technology.

A study in Ethiopia applied self-regulation techniques to increase the use of household fluoride filters[13] (see also ref. [72]). 'Specific planning' of the filter use and 'social prompts' indeed resulted in increased use.

To our knowledge, no study has yet aimed at promoting perceived fairness, trust or psychological ownership to increase the use of decentralized treatment technologies. As to ownership, a promotion study in Nepal failed in increasing ownership of community-based piped drinking water supply[76] (Box 3).

## An initial user-focused ToC

Most of the determinants of the use of decentralized treatment technologies identified in our review are in line with the RANAS factors[11]. However, our review also suggested several potential determinants that extend or go beyond the RANAS factors, namely (1) perceived risks resulting from using a technology[39,41–44], (2) perceived fairness[44,65], (3) trust in relevant actors[44] (for example, operators) and potentially trust in the technology, and (4) psychological ownership[48]. On the basis of these findings, we propose an initial user-focused ToC for the use of decentralized treatment technologies that considers both the original RANAS factors and these additionally identified determinants (Fig. 2). Furthermore, the ToC depicts how change techniques are expected to promote use by changing these determinants. As such, the ToC can serve as a tool to guide promotions to increase use. Finally, the ToC shows the environmental and health impacts which the use of decentralized treatment technologies aims at.

While the RANAS model[11] served as a starting point, the proposed ToC differs from the RANAS model in important ways. First, building on and extending research in the field of energy technologies[8], our ToC differentiates between different types of use (Box 1): 'passive' use, rooted in acceptance, 'engaged' use, rooted in support, and 'active' use, requiring behaviour change and rooted in behavioural intention[77]. The differentiation seems particularly important as the different types of use, or rather their direct antecedents acceptance, support and behavioural intention, are assumed to have partly different psychological determinants. Specifically, psychological ownership[78,79] and perceived ability are assumed to be decisive for support and behavioural intention only as both determinants might support people in engaging in individually costly acts that 'engaged' and 'active' but not 'passive' use may require. Self-regulation, in turn, is assumed to determine behavioural intention only (or 'active' use directly; see ref. [80]) as only

**BOX 3**

# The role of psychological ownership of water technologies for their sustainability

Individual and collective psychological ownership of an object, such as a water technology, is defined as the degree to which an individual or a group of individuals feels as though the object is 'theirs'[78,79]. The feeling may be based on legal ownership, in which case ownership is also societally recognized. However, it may also emerge without any legal rights or responsibilities towards the object, in which case ownership is foremost recognized by the individuals who feel ownership.

The concept of psychological ownership originates from organizational psychology. There, psychological ownership of one's job or organization was found to be associated with attitudes and behaviours that support organizational well-being[78,79], including pro-social acts and behaviours that are individually costly but vital for the well-being of the organization[97]. A study on community-based purification technologies in Kenya suggests that psychological ownership of technologies might also strengthen pro-social, individually costly acts that serve the technology's sustainability and thus the collective well-being[48]. Specifically, the study on safe water kiosks (see image; credit: Nadja Contzen; for the technology, see ref. [88]) found stronger feelings of collective ownership of the kiosks to be associated with higher use during the rainy season.

Using kiosks during the rainy season is individually costly because during the rainy season, rainwater harvesting is a much cheaper source of drinking water. However, it is collectively beneficial because widespread switching to rainwater harvesting threatens the economic viability of the kiosks.

Moreover, research on other shared water infrastructure found stronger feelings of collective ownership to be associated with higher functionality of the infrastructure[68]. However, this was the case only for feelings of ownership of water committee members but not of users. This is most likely because infrastructure functionality particularly profits from stewardship[78,79] and self-sacrificing behaviour[78,79] by committee members in the form of exemplary monitoring and maintenance of the technology.

Ownership seems thus particularly important for motivating people to engage in individually costly acts that serve a technology's sustainability. Therefore, we expect ownership to be the more important, the more demanding the monitoring and maintenance of a technology is.


**Roots of psychological ownership.** Given that research indicates psychological ownership to be an important driver of technology use and of pro-social behaviour that ensures a technology's sustainability, a key question is how the feeling of psychological ownership can be strengthened. Correlational research on community-based purification technologies[48] and other shared water infrastucture[95,98] suggests that people's decision power[48,95,98] and knowledge[95] about the technology as well as their cash or labour contributions[98] to the technology or infrastructure increase felt ownership. However, in a recent intervention study on shared water infrastructure, participatory activities targeting these factors did not increase felt ownership of the infrastructure[76]. The roots of ownership—and particularly the potential effect of cash or labour contributions—should be further researched as the commonly applied intervention of providing material (for example, refs. [3,12,73]) could unintentionally weaken felt psychological ownership.

'active' use implies a change in behaviours and routines, which requires self-regulation. The fact that 'passive', 'engaged' and 'active' use might have partly different determinants also implies that partly different change techniques might be required to support 'passive', 'engaged' and 'active' use.

Second, in two cases, our ToC considers more discrete determinants than the RANAS model[11]. Instead of attitude factors, our ToC considers (1) perceived costs and benefits and (2) affective reactions. The latter seemed to deserve a more prominent role as the feeling of disgust appeared as a key barrier to reuse[52–55]. Moreover, social norms and personal norms are considered separate determinants, primarily as they have different roots[81,82].

Third, next to psychological and behavioural outcomes, our ToC includes a technological outcome, namely, the sustainability of technologies[68]. It represents the durability and functionality of the system and is assumed to be facilitated by adequate OMM, which is supported by 'engaged' use and is an integral aspect of 'active' use. Sustainability, in turn, will facilitate long-term use.

The focus of the ToC (like that of the RANAS model[11]) is on psychological determinants of use as they explain why a certain change technique or activity is expected to result in use. Nevertheless, and following the revised version of the RANAS model[23], we included contextual factors[83]. Contextual factors are assumed to have two effects[23]. First, they may affect the psychological determinants[31,38,84]. For example, economically poor households may feel (and be) less able to use expensive technologies and may perceive them as more costly. Second, contextual factors may affect the paths of change. For example, providing complex medical information may increase health knowledge for a highly educated person but be ineffective for an illiterate person who may be challenged by the medical terminology.

Our ToC is considered initial because, overall, the evidence is still too limited to conclude on the key determinants of use and on effective change techniques to increase use. Importantly, the ToC might include potential determinants that, when the evidence increases, are revealed to be of minor importance and should thus be removed. When removing determinants, it should be considered, however, that

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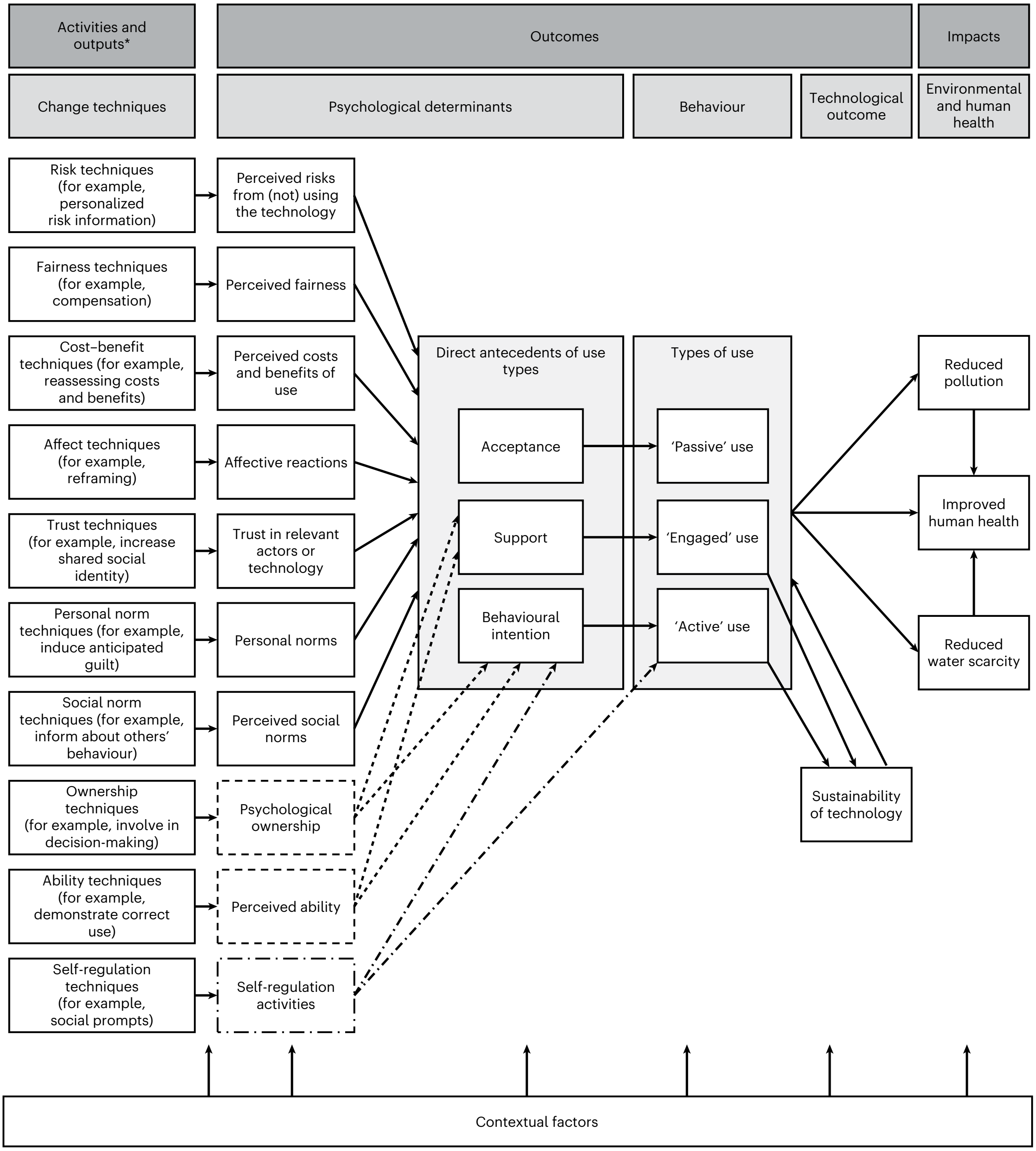


**Fig. 2 | Theory of change.** Pathways leading from change techniques via key determinants to acceptance, required for 'passive' use of, support, required for 'engaged' use of, and behavioural intention, required for 'active' use of decentralized treatment technologies. Dashed lines, psychological determinants assumed to determine support and behavioural intention only; dash-dotted lines, psychological determinant assumed to determine behavioural intention only as well as 'active' use directly. *In the present context, outputs represent different promotions that are made up by their content and their delivery channels. The content is defined by the applied change technique(s), such as providing personal risk information and prompting public commitment. These may be brought to the users through different (communication) channels, such as posters, community meetings or household visits.

the proposed determinants differ in their specificity: some represent broader, unspecific concepts (for example, costs and benefits), others much narrower, specific concepts (for example, social norms). It is likely that determinants representing broader, unspecific concepts will receive comparably more supporting evidence as there are, for example, a diverse number of costs and benefits that can be tested in parallel. Narrower, specific concepts, however, will probably receive comparably less supporting evidence as there are, for example, only a limited number of social norms that can be tested in parallel.

## The way forward

First and foremost, our review highlights a lack of (conclusive) evidence on the determinants of the use of decentralized treatment technologies and especially on change techniques to promote use. To increase the evidence, we call on environmental and health psychologists to intensify their research on both explaining and promoting the use of decentralized treatment technologies, considering the following recommendations. Future research aimed at explaining use should prioritize studies on reuse systems over purification technologies and focus particularly on LMICs as this research is especially limited.

Thereby, rather than testing a few potential determinants per study, as has been done so far (Table 2), scholars should consider the multitude of potential determinants comprehensively to test their relative importance[11]. This applies also to research on purification technologies, which should also consider the potential determinants that have been particularly understudied, such as perceived risks resulting from using the technology or trust in relevant actors (for example, operators of shared technologies) and in the technology.

For both technologies, research aimed at explaining use should apply at least correlational designs and, if possible, experimental designs to test causality[85]. Further, we call for investigating the relations between different determinants of use (for example, ref. [48]) as this knowledge might inform the selection of change techniques: if, for example, trust in operators is found to determine risk perceptions (see ref. [52]), promotions might profit from targeting trust instead of risk perceptions directly.

Further, future research should be more explicit about whether the specific technology and form of implementation requires acceptance/'passive' use, support/'engaged' use or behavioural intention/'active' use. Building on this, matching measures should be applied (see ref. [8]) and the relevant determinants considered (Fig. 2). Moreover, and especially regarding reuse systems, research should move from studying the most direct antecedents of use, that is, acceptance, support and intention, to studying actual use (see ref. [69]).

In addition, research aimed at promoting the use of decentralized treatment technologies is even more urgently needed, particularly regarding reuse systems. Future experimental studies should focus first on testing the effectiveness of single change techniques before testing entire promotion campaigns. For both steps, studies should provide detailed information on the applied change techniques to allow replications and application in practice.

Moreover, contextual factors[83], such as technological configurations and implementation characteristics (for example, scale), should be considered as they constitute the embedding in which use will happen. Importantly, contextual factors may serve as change techniques and should be tested as such. For example, while providing risk information could be one approach to reducing perceived health risks involved in using reuse systems, another promising option could be to install online sensors[86] that provide users with real-time information on the water quality. However, such sensors are only likely to promote use if users know how to react in the case of insufficient water quality and feel able to do so, which could be supported by ability techniques[23]. Thus, technological change techniques should always be combined with psychological ones to ensure effectiveness. To conclude, it seems necessary that engineers developing decentralized treatment technologies, psychologists testing promotions, and practitioners implementing technologies and promotions intensify collaboration to ensure that technologies, implementation and promotions are not only synchronized but also truly integrated.

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## Author contributions

Authors are ordered according to their contributions. N.C. led the conception and the writing of the manuscript. J.K. contributed to the conception and to all parts of the manuscript, and led the writing of the sub-sections on decentralized reuse technologies. H.J.M.

contributed to the conception and the writing of the sub-sections on purification technologies and provided feedback to all parts.

## Competing interests

The authors declare no competing interests.

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