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# Mindsponge-based investigation into the non-linear effects of threat perception and trust on recycled water acceptance in Galicia and Murcia, Spain

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***Abstract:***

**The water scarcity crisis is becoming more severe across the globe and recycled water has been suggested as a feasible solution to the crisis. However, expanding the use of potable and recycled public water has been hindered by public acceptance. Previous studies suggest threat perception and trust of provided information have positive linear relationships with recycled water acceptance. However, given the complex filtering role of trust in the human mental process, we argue that the effects of threat perception and trust may have non-linear relationships with acceptance of recycled water for drinking. To support and validate this argument, we employed Bayesian Mindsponge Framework analytics on 726 Spanish residents. We found that individuals more concerned about water shortage are less likely to accept using recycled water for drinking if their trust in the water quality and safety is low. Meanwhile, people more concerned about water shortage are more likely to accept using recycled water for drinking if they trust the water quality and safety. The findings suggest the non-linear relationships between threat perception, trust, and recycled water acceptance while validating mindsponge-based reasoning. Moreover, the results also highlight the importance of trust in influencing the mental process's outcome: recycled water acceptance.**

***Keywords:*** **non-linear relationship, recycled water acceptance, Spain, threat perception, trust.**

***Classification numbers:*** **1.4, 7**

## 1. Introduction

The global water scarcity crisis is increasingly severe due to more frequent and prolonged droughts induced by climate change, unprecedented population growth, and rapid economic development all resulting in increased water supply needs. For example, a large share of freshwater (ca. 70%) is needed for the agricultural sector [1]. Human anthropogenic activities, such as deforestation and depletion of environmental resources, have seriously reduced the quantity and quality of naturally available water sources. Though the natural recycling process is closed, human-related activities might block natural water flow via their negative interventions in natural water bodies such as rivers, lakes, groundwater, and wetlands [2]. It is expected that 1,800 million people in the world will live in areas with serious water scarcity and more than 60% of the world population might be under dire conditions of water shortages. One of the remarks being stressed on the Food and Agriculture Organization (FAO) webpage is, "If we don't change our habits now, global demand for water could increase by 50% by 2030", which is not too far from now [3].

The use of recycled water is real and present in many parts of our planet. It raises extensive concern

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from multiple stakeholders, especially the public, the end user of water [4], indicating an urgent need for alternative water sources. This issue leads to local, national, and international calls for effective measures to reduce pressure on water demand (e.g., reducing daily water consumption) and water suppliers. Out of potential alternative water sources, e.g., stormwater, greywater, seawater, and wastewater, recycled wastewater seems to be a cost-effective and environmentally friendly solution thanks to scientific and technological development [5, 6].

Despite recycled wastewater's feasibility and positive effects, its acceptance by the public community is still limited. Wastewater is water drained from human excretion to municipal wastewater, such as water from toilets, bathrooms, kitchens, and laundry. The public queries the health-related quality of reclaimed water and places trust in the clarity of information related to the process of water recycling. Firstly, recycled water could contain miscellaneous deposits of household or garden toxins or pharmaceuticals [2]. Secondly, this water might be contaminated with toxic or dangerous microorganisms that cause infectious diseases. Thirdly, the presence of organic compounds in recycled water could pose future health risks (e.g., pharmaceuticals and pesticide residues). Fourthly, hazardous chemicals might be produced during the water recycling process, possibly not fully eradicated and/or formed in water recycling systems [7].

Due to these potential problems induced by recycling wastewater, community residents are likely to reject or feel dissatisfied with recycled water if there exists concern about its quality [8], safety and reliability [9], recycled water's origins, failure in communication between water authorities and the community, lack of transparency and misunderstanding of water users in the technologies and recycling procedures, and individuals' perceptions of water shortage issues [10]. Recycled water seems to be accepted much more readily for low body contact purposes such as irrigation, watering gardens, and toilet flushing, but very limited in potable water uses (i.e., drinking and cooking). Particularly, the concept of drinking wastewater has not been supported by the public, resulting in the public rejection of water recycling campaigns [4, 5]. In addition, the perceived health risks of drinking recycled water, inadequate distribution infrastructure for supply, cheap potable water resources, and low community awareness of the water crisis have exacerbated the public denial of recycling water schemes [2, 11].

The low acceptance or strict opposition of the public towards recycled water has led some proposed potable wastewater reuse projects to be ineffectively implemented or abandoned, such as the 1995 East Valley Water Recycling Project in Fernando Valley, Los Angeles and a 2006 recycled water project in Toowoomba, Queensland, Australia [4]. Based on an objective analysis method by reviewing 910 articles screened from the Web of Science Core Collection from 1990 to 2020, L. Li, et al. (2021) [4] revealed that public health and public acceptance are among the hot topics and frontiers of research in water recycling literature, which reveals these issues existing in the society.

Many studies have been conducted to examine the determinants of recycled water acceptance among residents. Evidently, the adoption and willingness to use recycled water are dependent on the individual's perceived severity or awareness of the current crisis, the perceived threat of future water shortages and the probability of water crisis [10], and personal trust in the provided information about the recycling systems, financial costs, the positive effect on the environment, and nutritional value of reclaimed water [8]. Generally, the relationships between threat perception and trust towards the recycling systems with recycled water acceptance tend to be viewed as linear.

However, from the psychological perspective of the mindsponge theory (detailed rationalization will be explained in the next section), recycled water acceptance can be deemed an outcome of a mental process in which trust plays as a "gatekeeper" that allows the absorption of trusted information related to recycled water and exclude distrusted information [12-15]. Therefore, the effects of perceptions related to recycled water, including the threat perception, on recycled water acceptance are conditional on the trust status. Because of this property of trust, we contend that the threat perception of water scarcity and trust in the presented information may have non-linear relationships with recycled water acceptance.

## 2. Methodology

We employed the mindsponge theory to rationalize the argument and use Bayesian inference to validate it empirically [16, 17]. Specifically, Bayesian Mindsponge Framework (BMF) analytics was utilized on S. Vila-Tojo, et al. (2022a) [18]'s dataset from 726 Spanish residents. S. Vila-Tojo, et al. (2022a) [18] generated a dataset to study the recycled water acceptance from two Spanish regions with opposite water scarcity levels. The dataset has been employed to examine the reasons for public acceptance or rejection of recycled water [19].

### *2.1. Mindsponge-based rationalisation*

According to the mindsponge theory [12, 20, 21], information must be viewed as valuable by the mind to exist and persist in an individual's mind. Based on the relevant information in the mind, new information is subjectively judged as beneficial or costly [22-25]. On the one hand, lacking water can result in inconvenience and fatality (one can die without drinking water for more than three days). However, the perceived risk of death might not be crucial in the studied population, as they are residents of Spain, a developed country. On the other hand, consuming recycled water is often perceived as costly due to the expectation of negative consequences and other underlying uncertainties derived from recycled water [26, 27]. In a mental process, these perceived risks might negate the perceived benefit of drinking recycled water.

The mindsponge theory suggests that trust also plays an important factor in the information process of the mind [12, 15, 28, 29]. If the mind trusts specific information, it is more likely to allow that information to enter the mindset and subsequently influence later thinking and behaviours. In this case, if people trust the quality and safety of recycled water, they are more likely to accept drinking recycled water while thinking that water shortage affects them directly. In contrast, if people distrust the water quality and safety, they may think and behave oppositely because distrust could make them ignore the option of drinking recycled water, intensifying the perceived impacts of water shortage on themselves.

Thus, we hypothesized that concern about water shortage is associated with the acceptance of drinking recycled water. Still, the association depends on the individual's trust level towards water quality and safety. This hypothesis indicates non-linear relationships between the threat perception and trust towards recycling systems with recycled water acceptance.

The following model is constructed to examine this hypothesis:

$$\text{DrinkRecycledWater} \sim \text{WSImpactSelf} + \text{WSImpactSelf} * \text{SafetyQualityTrust}$$

The description of the variables is presented in Table 1. The logical network of the constructed model is displayed in Fig. 1.

**Table 1. Variable description.**

| Variable | Description | Data type | Coding |
|---|---|---|---|
| DrinkRecycledWater | Agreement with that I use recycled water for drinking | Continuous | 0 (strongly disagree) - 10 (strongly agree) |
| WSImpactSelf | Agreement with that I am concerned that the water shortage will affect me personally | Continuous | 1 - strongly disagree<br>2 - disagree<br>3 - neutral<br>4 - agree<br>5 - strongly agree |
| SafetyQualityTrust | Agreement with that I trust that they guarantee the safety and quality of water | Continuous | 1 - strongly disagree<br>2 - disagree<br>3 - neutral<br>4 - agree<br>5 - strongly agree |

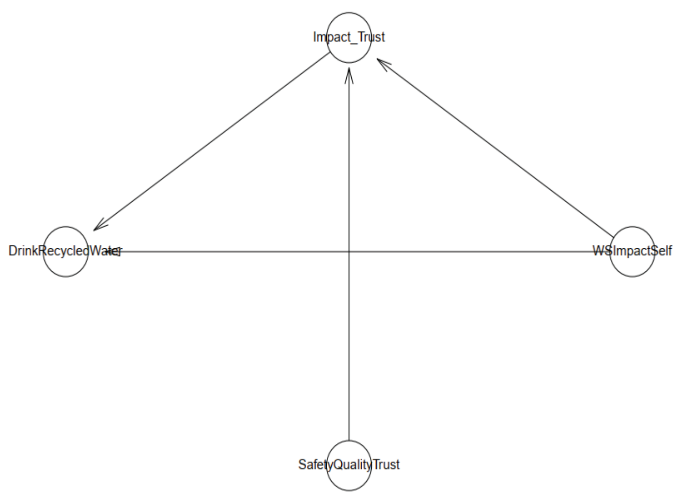


**Fig. 1. The logical network of the constructed model.**

### *2.2. Materials and methods*

The dataset was collected from two Spanish regions with different levels of water scarcity: Galicia, with an average rainfall of 197 l/m², and Murcia, with an average rainfall of 29 l/m² during October 2019. Galicia is a region located in northwest Spain with approximately 2.7 million residents, while Murcia is situated in south-eastern Spain with almost 450 thousand residents. Participants were chosen via proportional random sampling based on gender and age. Those who fit the necessary profile (by gender, age, and place of residence) were contacted via email between October 2 and 23, 2019, by a market research firm. In compensation for their responses, the firm rewarded the respondents monetarily. They were given a link to an online questionnaire that took around 15 minutes to complete [18]. All participants gave consent before completing the questionnaire. The University of Santiago de Compostela's bioethics committee approved the study. In total, the survey collection resulted in a dataset of 726 responses, in which 50.1% of the samples were males, 49.45% resided in Galicia, and their mean age was 43.90. S. Vila-Tojo, et al. (2022b) [19]'s statistical analysis showed that the respondents' sex, educational level, employment status, and monthly income in the two study regions were not significantly different.

From the dataset, variable A16, indicating the respondents' thinking of whether they would agree to use recycled water for drinking, was selected as the outcome variable. We selected this variable in the current study as drinking recycled water is the most concerning way of using recycled water. If our postulations are applied to drinking recycled water, they might be applicable to other ways of using recycled water. Variables TP3 (demonstrating the residents' concern about the impacts of water shortage on themselves) and TS1 (demonstrating the residents' trust towards water quality and safety) were selected as predictor variables to check the validity of the mindsponge theory (Table 1).

Bayesian analysis was conducted using the bayesvl R package due to its user-friendly operation method, capacity to visualize eye-catching graphics, and cost-effectiveness [30, 31]. Moreover, the Bayesian analysis is aided by the Markov Chain Monte Carlo (MCMC) method, so it can be applied for a wide range of models, resulting in substantial flexibility [32, 33]. The models were fitted with four Markov chains. Each chain included 5,000 iterations of which the first 2,000 were set as warmup iterations. As the analysis was conducted to check whether the mindsponge theory is valid empirically, we employed uninformative priors for the analysis to avoid subjective bias.

The model's robustness is examined in two ways. First, Pareto smoothed importance-sampling leave-one-out cross-validation (PSIS-LOO) was employed to check the model's goodness-of-fit [30, 34]. The model's goodness-of-fit can be classified into four levels: 1) 'Good' if its k-values are all below 0.5; 2) 'OK' if its k-values are more than 0.5 and below 0.7; 3) 'Bad' if its k-values are more than 0.7 and below 1; and 4) 'Very bad' if its k-values are more than 1. Next, we checked the Markov chain central limit theorem using two diagnostic statistics: effective sample size (n_eff) and Gelman-Rubin shrink value (Rhat). If the n_eff values are larger than 1,000 and the *Rhat* values equal 1, they will imply good convergence of Markov chains parameters [35, 36]. The Markov chain convergence was also validated visually using trace plots, Gelman-Rubin-Brook plots, and autocorrelation plots.

## 3. Results

Before interpreting the simulated posterior distributions based on the model constructed above, it is necessary to check the model's goodness-of-fit. As can be seen from Fig. 2, all the k-values are below 0.1, suggesting that the constructed model is a good fit for the data.

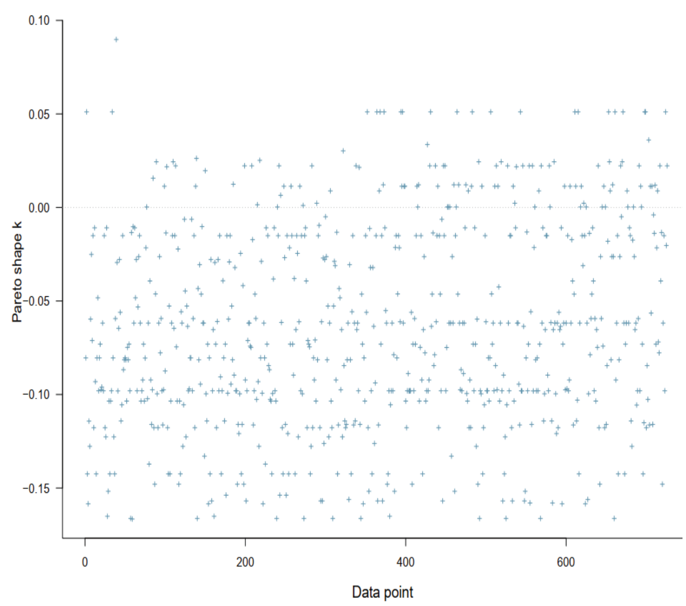


**Fig. 2. PSIS diagnostic plot of the constructed model.**

Both the n_eff values (larger than 1000) and Rhat values hint at the model's good convergence (Table 2). The Markov chains in Fig. 3 further confirm the convergence of the model.

**Table 2. Simulated posterior results.**

| Parameters | Mean | SD | n_eff | Rhat |
|---|---|---|---|---|
| Constant | 1.90 | 0.36 | 6498 | 1 |
| WSImpactSelf | -0.16 | 0.12 | 5765 | 1 |
| WSImpactSelf* SafetyQualityTrust | 0.04 | 0.02 | 6498 | 1 |

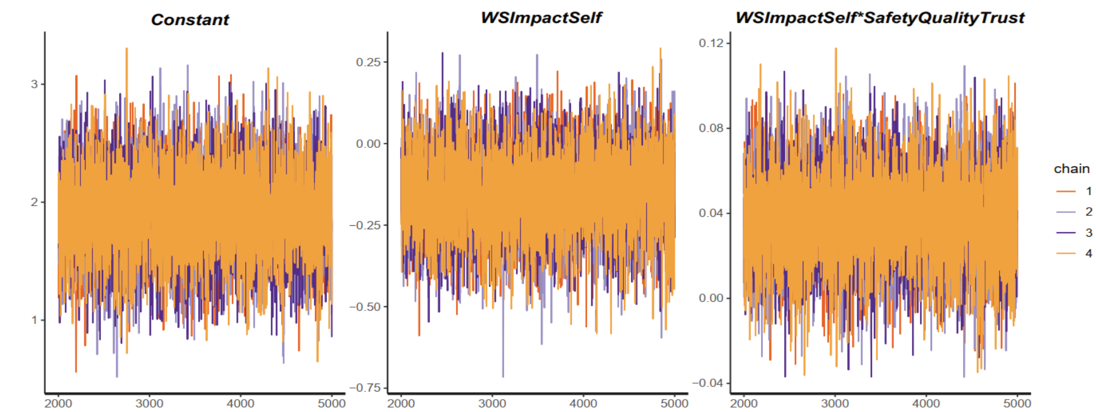


**Fig. 3. Trace plots of the constructed model.**

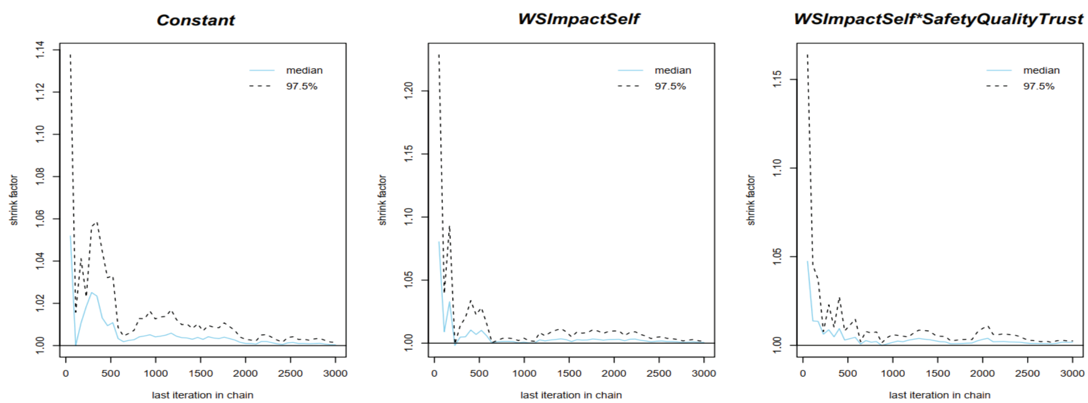


**Fig. 4. Gelman-Rubin-Brook plots of the constructed model.**

Similarly, the model's convergence signals can also be observed in the Gelman-Rubin-Brook plots (Fig. 4) and autocorrelation plots (Fig. 5). Specifically, the shrink factors in the Gelman-Rubin-Brook plots rapidly decrease to one before the warming phase completes (before the 2,000$^{th}$ iteration), while the autocorrelation levels rapidly decrease to 0 after a specific number of lags (well below 5) in the autocorrelation plots.

From the analysis, we found that the residents' concern about the water shortage impacts on themselves is negatively associated with their acceptance of using recycled water for the sake of drinking (=-0.16 and =0.12). The association is positively moderated by the residents' trust in the recycled water quality and safety (=0.04 and =0.02). These associations are reliable, as most of their posterior distributions are located on one specific side of the origin (Fig. 6). Indeed,  distribution is on the left, and  distribution is on the right.

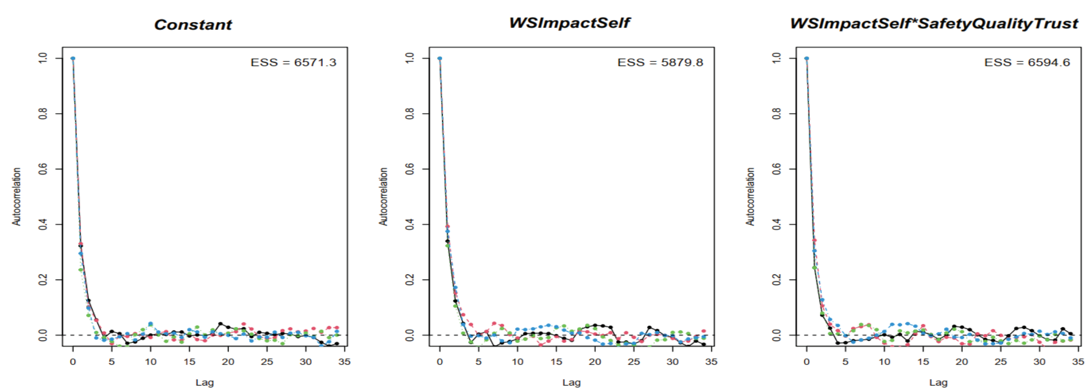


**Fig. 5. Autocorrelation plots of the constructed model.**

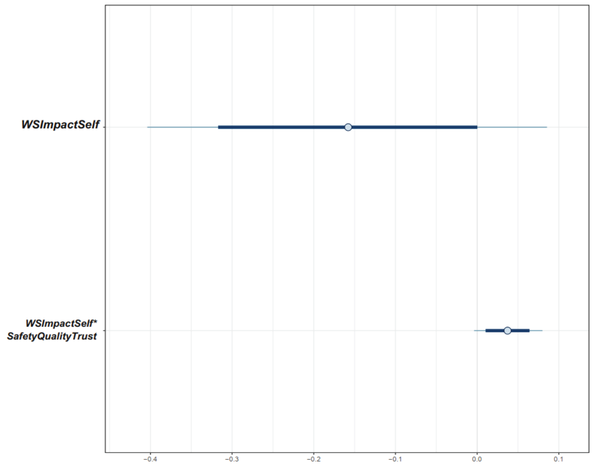


**Fig. 6. Posterior distributions of the constructed model.**

As it may not be obvious to interpret the results in terms of coefficients, we visualized them in Fig. 7 for better comprehension. The *x*-axis represents the concern about water shortage, and the *y*-axis indicates the agreement of the respondents towards using recycled water for drinking ranging from 'strongly disagree' (0) to 'strongly agree' (10). People with more concerned about water shortage are less likely to accept using recycled water for drinking if their trust in the water quality and safety is low. Whereas, people more concerned about water shortage are more likely to accept using recycled water for drinking if their trust in the water quality and safety is high. These findings support the non-linear relationships between recycled water acceptance, threat perception, and trust towards provided information that are rationalised based on the mindsponge theory.

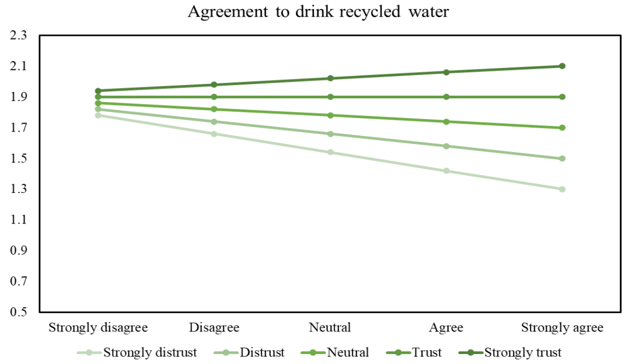


**Fig. 7. Recycled water usage acceptance in relation to the concern of water shortage and trust towards the recycled water.**

## 4. Discussion

The current study employed Bayesian Mindsponge Framework analytics on the dataset of 726 Spanish residents' recycled water acceptance to examine the non-linear relationships between recycled water acceptance, threat perception, and trust. The estimated results suggest that the mental process leading to the acceptance of recycled water is complex and non-linear, validating mindsponge-based reasoning.

Specifically, we found that threat perception due to water shortage has a positive impact on recycled water acceptance for drinking only in scenarios where residents trust the safety and quality of water. If the residents have low trust in water safety and quality, the threat perception adversely affects the recycled water acceptance. Employing mindsponge theory reasoning can help explain these findings [12, 21]. People more concerned about water shortage might also be those more sensitive to water issues, including recycled water safety and quality. Therefore, if they distrust the provided information, their concerns about recycled water safety and quality might be exacerbated. In this case, not drinking recycled water might be deemed more beneficial for them, leading to lower acceptance. Some might argue that water shortage can be fatal for the residents, so drinking recycled water is a better option than death from dehydration. This is reasonable, but only for those with no alternative to recycled water. It should be noted that the samples analysed in the current study were collected in Spain, a developed country, so even though there is a water shortage, the residents might be able to find substitute water sources.

As can be seen in Fig. 7, even when people strongly trust the provided safety and quality information and are strongly concerned about the water shortage, their acceptance score (around 2.1) is still much lower than the threshold of acceptance for using recycled water for drinking. The threshold is around 5 because the acceptance scale ranges from 'strongly disagree' (0) to 'strongly agree' (10). This low acceptance level might be attributed to bad perceptions of recycled water. Recycled water is often generated from water drained from human excretion to municipal wastewater, such as toilets, bathrooms, kitchens, and laundry. Thus, residents might relate the perception of "dust" or "waste" when thinking about recycled water, creating a subjective barrier to accepting this sort of water, especially for drinking.

However, our results show that improving the recycled water acceptance among residents is possible by simultaneously exposing them to the threat of water shortage and building their trust in the safety and quality of recycled water. Frequently communicating the current situation and risks of water shortage in the region will help raise the residents' perceived threat of water shortage. At the same time, a long-term trust-building process is also needed to convince users about the safety and quality of recycled water.

Residents' trust can be built by being transparent about the information related to recycled water and ensuring the provided information is correct and persistent [13, 37]. For example, answering questions of why water should be recycled; how it is recycled; the safety of the water for various purposes including cooking and drinking; and how it has been used. N. Roseth (2008) [38] found that Australians provided with such information were more willing to use recycled water for multiple purposes (including cooking and drinking) and had more positive and less negative attributes associated with recycled water. Moreover, providing two-sided information related to recycled water (positive and negative effects of recycled water) is more effective at increasing residents' trust in the government and recycled water support than providing one-sided information (only positive effects) [39]. Trust can also be improved by enhancing the source's credibility or the perceptions of the water authority's competence and consideration for the community's interests [40].

The current study is not without limitations, so they are presented here for transparency [41]. First, we only tested the non-linear relationships between recycled water acceptance for drinking, threat perception, and trust, so whether the non-linear mental process leading to recycled water acceptance applies to other types of water usage will need further confirmation. Second, the analysed samples were collected in only two Spanish regions, Galicia and Murcia, so they might not adequately represent the Spanish population or other countries. Thus, the current study's results should be interpreted with caution.

## 5. Conclusions

This study utilised the Bayesian Mindsponge Framework and a dataset consisting of 726 respondents regarding the acceptability of recycled water among Spanish residents in order to probe the dynamic association between recycled water acceptance, threat perception, and trust. The estimated results corroborated the mindsponge-based reasoning, suggesting that the mental process leading to the acceptance of recycled water is complicated and non-linear. Particularly, we discovered that people's trust in the quality and safety of water is required for water scarcity perception to positively affect recycled water acceptability for drinking. Residents' sense of risk reduces their willingness to use recycled water if they have low trust in its safety and quality. Based on these findings, we suggest that people's willingness to use recycled water can be increased by simultaneously making them aware of the dangers of a water shortage and reassuring them of the quality and safety of recycled water.

## CRediT author statement

Minh-Hoang Nguyen, Tam-Tri Le, Quan-Hoang Vuong: Conceptualization; Minh-Hoang Nguyen, Thi-Phuong Nguyen, Hong-Son Nguyen: Methodology; Viet-Phuong La: Software; Quan-Hoang Vuong: Validation, Supervision, Project administration; Phuong-Loan Nguyen, Minh-Hieu Thi Nguyen: Formal analysis; Minh-Hoang Nguyen, Tam-Tri Le, Phuong-Loan Nguyen, Minh-Hieu Thi Nguyen: Investigation; Minh-Hoang Nguyen: Resources; Tam-Tri Le: Data curation; Minh-Hoang Nguyen, Thi-Phuong Nguyen: Writing - original draft preparation; review and editing; Viet-Phuong La, Hong-Son Nguyen: Visualization.

## COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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