Navigating end-user perceptions: development and initial psychometric properties of a water quality perception scale

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Consistent and accurate measurement of public perceptions of water quality is useful for understanding water use behaviors, policy development/support, and community engagement, all essential for sustainable water management. Toward consistent and accurate measurement, we refined and examined the initial psychometric properties of a Water Quality Perception Scale (WQPS). In this study, we report an exploratory factor analysis (EFA) with 18 items on a group of respondents ($N = 154$), which identified one primary factor, 'Individual Water Quality Perception,' consisting of 13 items and two additional factors represented by the remaining 5 items. Subsequently, a confirmatory factor analysis (CFA) was performed with ($n = 147$ participants), including both original ($n = 74$ assessed at a separate time from their original assessment) and new participants ($n = 73$). The results of the CFA affirmed the initial loadings of the 13-item WQPS in a single factor. The scale demonstrated internal consistency, with coefficients of 0.93 and 0.90 (Cronbach's alpha) in the two samples, and the measure showed convergent validity with the Household Water Insecurity Experiences Scale (HWISE), ($r = -0.41$ and -0.49 in the respective samples). This scale holds promise toward consistent and accurate measurement instrument for researching public perceptions of water quality, guiding policy and public initiatives to improve water management strategies. Avenues for further development and use are discussed.

KEYWORDS

water quality perceptions, scale development, water insecurity, end-user perception, factor analysis

Introduction

Water quality, encompassing water's physical, chemical, and biological attributes, remains a cornerstone of environmental sustainability, public health, and economic development (Duan et al., 2013; Gholizadeh et al., 2016). The United Nations' Sustainable Development Goal 6 exemplifies the global emphasis on drinking water quality, which seeks to "ensure availability and sustainable management of water and sanitation for all" (Hoekstra et al., 2017). Nevertheless, the public's understanding and perception of water quality often diverge from the objective measurements of scientists and policymakers (Eden, 1996; Pacione, 2003;

Doria, 2010). This mismatch can result in non-optimal water-related behaviors, suboptimal policy support, and public resistance to critical water initiatives (Grey et al., 2013; Nelson et al., 2023).

Myriad water quality problems can affect public perception. While commendable strides in improving water quality have been made, high-profile incidents, like the lead-contaminated water crisis in Flint, Michigan, can dominate public discourse even in the most industrialized countries (Pauli, 2020). Moreover, other communities across the United States, including Newark, New Jersey, and Jackson, Mississippi, have faced water-related crises (Yang and Faust, 2019; Kim et al., 2023). These situations not only spotlight the immediate health concerns but also lead to heightened distrust in authorities and a skewed perception of overall water quality in the nation. Water quality perception involves the process through which individuals pick, structure, and decode sensory information to construct a coherent understanding of their water quality (Auslander and Langlois, 1993; Heekeren et al., 2008; Hu et al., 2011; Alhassan and Kwakwa, 2013). It confluences an individual's experiences, deeply ingrained cultural beliefs, educational background, and prevailing media narratives (Tuan, 1990). Even if objective measures indicate that water is safe for drinking, significant mistrust or concerns over quality can lead to notable consequences, ranging from reduced consumption to increased reliance on unsustainable bottled water (Doria, 2006, 2010).

A gap between perception and reality can have tangible consequences. Distrust in public water systems can lead to increased bottled water consumption, which has environmental implications and places a financial burden on households (Nelson et al., 2023). Misconceptions about water quality can lead to negative public behaviors, hindering the implementation of necessary water infrastructure upgrades or pollution control measures (Pierce and Gonzalez, 2016). Indeed, Sarkar (2022) has suggested including a module of questions in the American Housing Survey (AHS) that would provide data to determine and track the link between the perception of water quality and local-level communication regarding it, the effectiveness of the frequency of receiving such information, and other factors that link perception and consumption (Sarkar, 2022).

Consistent and accurate measurement of water quality perceptions is needed. Such assessments are at an important intersection between the engineering, social, policy, and human aspects of water security and sustainability (Weems et al., 2023). While qualitative approaches such as interviews and focus groups offer depth, they are often constrained in scope and scalability (Goss and Leinbach, 1996; Agunbiade and Ogunleye, 2012; Davis et al., 2019). Their inherent design often limits their applicability to smaller, targeted populations. This poses challenges in generalizing findings or scaling up these methods for broader regional or national assessments. However, it is important to recognize the evolving methodologies within qualitative research that address these limitations. Various studies have demonstrated innovative methods to scale qualitative data, leveraging technologies and mixed-methods approaches that enhance data collection, analysis, and generalization capabilities (Zachariadis et al., 2013; Crespo et al., 2021). This includes the use of digital platforms for wider participant recruitment, software for data analysis, and strategic integration with quantitative methods to broaden the scope of research findings (O'Connor et al., 2016; Rupert et al., 2017).

Questionnaires, often structured and closed-ended, can be developed based on insights from qualitative work to assess large samples (Doria et al., 2009; Levêque and Burns, 2017). Conversely, responses from these questionnaires can guide the design of qualitative approaches for deeper insights (Braun et al., 2021). However, a lack of standardization in question framing, response scales, and thematic focus can lead to inconsistencies, making it challenging to conduct cross-comparative analyses or aggregate data from different studies. Furthermore, while water infrastructure decisions are often local, the factors influencing public perceptions of water quality can have regional or national resonance (Alhassan and Kwakwa, 2013; Pierce and Gonzalez, 2016; Yang and Faust, 2019). Factors such as environmental policies and media narratives can greatly influence public perception on a larger scale (Heekeren et al., 2008).

Research helping to move toward a consistent and accurate measurement instrument of water quality perceptions is needed, similar to the work done on "water insecurity" with the Household Water Insecurity Experiences (HWISE) Scale developed by Young et al. (2019). The HWISE is used in several contexts to understand water insecurity and facilitate consistency assessment across studies. To this end, this study aimed to provide initial psychometric data on a Water Quality Perception Scale (WQPS). To facilitate consistency, a large portion of the items selected for analysis in this study were initially included in a study by Doria et al. (2009). Their paper explored the influence of organoleptic properties (taste, smell, and color) on perceptions of tap water quality (Doria et al., 2009). The items from Doria's study were adapted, sometimes directly and sometimes with modifications, to fit a broader context, attempting to make them relevant across diverse geographic and cultural environments. In the original work by Doria et al. (2009), the items were treated as separate individual indicators; however, this paper aimed to determine if these items comprise a unitary or multifaceted construct of "water quality perception." In other words, can a set of items from tap water quality perceptions be considered separate indicators?

Data collection for this particular project was conducted in Puerto Rico. Acknowledging the significant impact of hurricanes on Puerto Rico's water infrastructure and quality (Brown et al., 2018; Mejia Manrique et al., 2021), the research team also developed items that address these specific challenges related to the hurricane season. Hurricanes and their aftermath play a substantial role in shaping the perception of water quality and safety. In Phase 1, we describe the development of the WQPS and explore its factor structure using exploratory factor analysis (EFA). We expected there to be a core set of items but that there may be additional factors from the initial set of items tested. In Phase 2, we use confirmatory factor analyses (CFA) to replicate the factor structure identified via the EFA analyses. We also examine the WQPS's association with a similar construct of water insecurity using the Household Water Insecurity Experiences (HWISE) Scale developed by Young et al. (2019). We predicted that the WQPS scale would be moderately (because water quality is similar but distinct from water insecurity) and negatively correlated with the HWISE (i.e., more water insecurity is associated with lowered water quality perceptions).

Methods

Initial instrument

Table 1 links each WQPS item to its source.

TABLE 1 Water quality perception scale items and sources.

Construct	Water quality perception scale items	Source
Quality	My tap water is usually of high-quality	Doria et al. (2009)
Risk	There are health risks associated with drinking water in my home from my tap*	Doria et al. (2009)
Taste	I am happy with the taste of my tap water	Doria et al. (2009)
Color	I am happy with the color of my tap water	Doria et al. (2009)
Odor	I am happy with the smell of my tap water	Doria et al. (2009)
Maintenance	The water pipes and taps of my home are clean and well-maintained	Doria et al. (2009)
Friends	Some friends told me negative comments regarding my tap water.	Doria et al. (2009)
Family	Some family members told me negative comments regarding my tap water	Doria et al. (2009)
Memorability	Tap water has caused health problems for me or for someone in my family	Doria et al. (2009)
Trust	I trust my water service company (e.g., AAA/PRASA)	Doria et al. (2009) and Nelson et al. (2023)
Familiarity	I am used to my tap water	Doria et al. (2009)
Pressure	I am satisfied with the tap water pressure in my home	Doria et al. (2009)
Lead/Chemical	My tap water is contaminated with lead or any chemicals*	Doria et al. (2009)
Chlorine	My tap water has too much chlorine*	Doria et al. (2009)
Hardness 1	My tap water has too much limescale*	Doria et al. (2009)
Hardness 2	My tap water is too hard*	Doria et al. (2009)
Hurricane 1	I am worried about the quality of water and water contamination (e.g., chemicals) during the hurricane season	Author construct
Hurricane 2	I am worried about the quality of water and water contamination (e.g., chemicals) after the hurricane season	Author construct

*Reverse coded items.

Respondents are asked to answer each of these 18 items on a 5-point Likert-type agreement scale from strongly disagree to strongly agree. To ensure linguistic accuracy, the survey was meticulously translated into Spanish by one of our authors, who is a native of Puerto Rico, thus ensuring cultural relevance and precision in our Spanish-language questionnaire. The administration of the survey was conducted by a team of four field research assistants, who ensured the quality and consistency of the data collection process throughout the study.

Participants were also administered the Household Water Insecurity Experiences (HWISE) scale which is a version of the Water Insecurity Experiences (WISE) scale series (Young et al., 2019). There are four versions of the WISE scales. The household (HWISE) and individual (IWISE) scales ask about the frequency of experiences with 12 common water-related disturbances to emotional well-being or disruptions in daily activities. The brief (HWISE-4) and (IWISE-4) scales are based on a subset of the 4 water-related experiences. The HWISE scale consists of a set of questions that are designed to capture the frequency of various experiences related to water insecurity over a recall period, such as water shortages, concerns about water quality, and the impact of water issues on food security. Example items include (*In the last 4 weeks, how frequently did you or anyone in your household worry you would not have enough water for all of your household needs*? and *in the last 4 weeks, how frequently has there been no useable or drinkable water whatsoever in your household?*) Each of the 12 items are scored 0 (never), 1 (rarely), 2 (sometimes), or 3 (often/always), for a total score range of 0–36. A score of 12 or more is considered water insecure for the HWISE. Research suggests the items are unidimensional in factor analyses and have internal consistency

estimates of Cronbach's alpha ranging from 0.84 to 0.93 (Young et al., 2019). Previous data further suggest equivalence of measurement and meaning across sites. Predictive, convergent, and discriminant validity are available in Young et al. (2019). Internal consistency in this sample was alpha = 0.88 in both phases of the study.

Sampling strategy and data collection

These data came from a larger study of repeated disasters on water insecurity and mental health outcomes in Puerto Rican communities. Puerto Rico is an ideal study area for this initial work because while the mainland USA has faced its share of water quality challenges, Puerto Rico, a U.S. territory, navigates an even more challenging situation. This is not solely a product of infrastructure or policy but is significantly amplified by natural hazards, particularly hurricanes (Brown et al., 2018; Kaufman, 2019). Historically, Puerto Rico has faced infrastructural challenges. Aging pipelines, wastewater treatment limitations, and compromised water sources have perennially influenced the island's water narrative (Mejia Manrique et al., 2021). The situation, complex in its own right, is exacerbated by natural hazards. Puerto Rico lies in a region frequently hit by hurricanes. Disasters like Hurricane Maria in 2017 not only affected the island's infrastructure but also critically impacted water quality. The heavy rainfall and flooding led to the overflow of sewage systems, the runoff of contaminants from damaged industrial sites, and the mixing of fresh water with salt water, all of which contributed to widespread drinking water contamination (Rosinger, 2018; Fischbach et al., 2020; Ghosh et al., 2021).

Data was collected in four municipalities: Loiza, Aguas Buenas, Comerio, and Utuado. Loiza, characterized by its Afro-Puerto Rican heritage, encapsulates economic disparities often overshadowed by Puerto Rico's more commercially celebrated regions (Nelson et al., 2023). A deep-seated economic marginalization in Loiza interfaces with water insecurity, necessitating a nuanced exploration. Aguas Buenas, ironically, which means "good waters" in Spanish, has been a hotspot for infrastructural challenges, especially post-hurricane devastations (Laskow, 2018). Both Hurricanes Maria and Fiona have strained its already fragile water distribution systems, inducing multifaceted adversities for its populace. The topographical intricacies of Comerio, which lies in Puerto Rico's mountains, lead to unique challenges. Access to consistent, clean water sources remains a perennial issue, further intensified during seasonal fluctuations (Marcos, 2022). Utuado's proximity to abundant water sources is marred by outdated water treatment. Despite its geographical proximity to freshwater sources, contamination and accessibility challenges are rampant (Holladay et al., 2021).

In the first phase of our research, we focused on the collection of survey data from 154 residents spanning three municipalities: Loiza, Comerio, and Aguas Buenas. These data were gathered prior to the devastating effects of Hurricane Maria from May 2022 to July 2022. Following the hurricane, Phase 2 was initiated, where we expanded our geographical scope to include an additional region, Utuado, following the low response rate from Loiza after Hurricane Fiona. Hence, the data for the second phase encapsulated survey data from 147 residents of Loiza, Comerio, Aguas Buenas, and Utuado, specifically after the impacts of Hurricane Fiona from September 2022 to February 2023. The methodologies and survey instruments implemented in both studies were reviewed and approved by the Institutional Review Board (IRB) of Iowa State University.

Data analysis

Phase 1: exploratory factor analysis

The 18-item items from Table 1 were initially analyzed using the pre-hurricane Fiona dataset ($N = 154$) with exploratory factor analysis (EFA) executed in STATA 15 statistical software. The principal axis factoring of the item correlation matrix using a Varimax rotation was used to simplify factor identification (Ohan et al., 2000; Janus and Offord, 2007). The varimax rotation was used to present a clearer, more discernible factor structure (Osborne, 2015). Maximizing the variance of the squared loadings ensures that items predominantly load onto a single factor, which considerably simplifies interpretation and subsequent utilization. Critical to the factor interpretation is the consideration of factor loadings. These loadings serve as markers, pointing toward the correlation strength between individual items and the identified constructs. Convention in the literature dictates that items with loadings above certain thresholds, often set at 0.3, significantly represent a specific factor (Beavers et al., 2013). It is through this lens that each item's relevance to the identified constructs was determined.

Phase 2: confirmatory factor analysis

Following the EFA results in Phase 1, we conducted a Confirmatory Factor Analysis (CFA) with the post-hurricane Fiona dataset ($N = 147$) to confirm the factor structure of the scale items.

This methodological approach tests the alignment of the proposed factor structure with the observed data (Luong and Flake, 2023). Initially, the factor model was specified based on insights from the EFA results and a robust theoretical foundation, wherein each item was systematically aligned to its hypothesized factor. Full Information Maximum Likelihood (FIML) approach was adopted for the analysis (Enders, 2001). We examined the model's fit with the data using multiple fit indices. Specifically, the chi-square statistic, Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR) were assessed against accepted benchmarks (Hu and Bentler, 1998). Modification indices were examined to discern potential enhancements, ensuring that any revisions were grounded both statistically and theoretically.

Convergent validity

The convergent validity of the WQPS scale was assessed by conducting Pearson correlations between the total WQPS scores and the total HWISE scores at both Phase 1 and Phase 2.

Results

Phase 1

Descriptive statistics

Table 2 reports the demographic characteristics of the participants in phase 1 of the study.

Correlation of WQPS items at phase 1

The Pearson correlation matrix in Figure 1 shows the relationships between the individual items of the initial 18-item WQPS. Coefficients range from −1 to 1, where 1 denotes a perfect positive correlation, −1 denotes a perfect negative correlation, and 0 indicates no correlation. The color gradient represents the direction and strength of these correlations: shades of blue indicate positive correlations, shades of red denote negative correlations, and the color's intensity reflects the correlation's magnitude. Most of these items indicate moderate to high correlation values among themselves. Such a pattern suggests the appropriateness of factor analysis (i.e., the items are factorable) and that each item correlated at an acceptable level with the total.

Exploratory factor analysis

The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was 0.895, a value suggesting adequate sample size (Kaiser, 1991). Furthermore, Bartlett's test of sphericity was significant ($p < 0.001$), thereby confirming that correlations between WQPS items were substantial enough to warrant factor analyses (Beavers et al., 2013). The data had a few missing values. Each item on the WQPS had between 0.65 to 9.74% missing.

A factor solution was obtained by considering Kaiser's criterion (retaining factors with eigenvalues greater than one), the interpretability of obtained factor solutions, and the internal consistency of obtained factors provided by STATA 15, which suggested a three-factor model. Each factor potentially represented distinct dimensions of people's perceptions related to water quality. Three factors with 18 items were extracted: (1) individual water quality perception (13 items); (2) external/family-induced water quality

TABLE 2 Demographics results of phase 1.

Variable	N	Descriptive statistics	Value	%
Age	154	Minimum	20	–
		Mean	62.83	–
		Median	66	–
		Maximum	93	–
Gender	154	Female	115	75%
		Male	39	25%
Education	154	No schooling completed	3	2%
		Elementary school degree	13	8%
		Middle school degree	14	9%
		High school diploma	72	47%
		Bachelor's degree	34	22%
		Associate's degree	14	9%
		Other/missing	4	3%
Race	154	White	46	30%
		Black/African American	46	30%
		Asian	0	0%
		Native Hawaiian/Pacific Islander	0	0%
		American Indian/Alaska Native	2	2%
		Mixed (5)	28	18%
		Other/missing (6)	32	20%

perception (3 items); and (3) hurricane-related water quality perception (2 items) (Table 3). Internal consistency (Cronbach's alpha) for factors 1 was 0.93; for factors 2 and 3, internal consistency was 0.84 and 0.73, respectively (see Table 3). We identified the first factor as a reliable subscale because Cronbach's a was larger than 0.9, which indicates excellent internal consistency (Cronbach, 1951; Taber, 2018).

Conceptually, factor 1 is comprised of items that directly reflect an individual's subjective assessment of their tap water quality. Central to this factor appear to be those that directly address the sensory qualities of the water (taste, color, and smell) and health-related concerns (presence of chemicals or contaminants like lead, chlorine, or limescale). These items are critical as they are likely to have a direct and significant impact on an individual's overall perception of water quality. Other items in this factor, like satisfaction with water pressure, trust in the water service company, and the condition of water pipes and taps, while still relevant, might be considered more peripheral. They contribute to the overall perception but might not be as directly influential as the sensory and health-related aspects. The high internal consistency of this factor suggests that these items when considered together, provide a comprehensive and reliable measure of an individual's perception of their water quality.

Despite the acceptable levels of internal consistency for factors 2 and 3, we encountered high skewness values that signaled a distributional bias in the responses (Dinno, 2009). Conceptually, factor 2 was external perception focused on the individual's perception – these are on what others thought about water quality, and factor 3 was situation-dependent focusing on the hurricane. Coupled with the limited number of items for factors 2 and 3, factors 2 and 3 appear to be in need of additional refinement and additional development.

Figure 2 shows the distribution curve of the total score of the 13-item WQPS at Phase 1.

Convergent validity

The Pearson correlation analysis revealed a correlation of -0.41 ($p < 0.01$) between the WQPS and HWISE scores. It suggests that when individuals have a high perception of their drinking water quality, they are likely to report lower levels of water insecurity, providing an estimate of convergent validity consistent with the prediction.

Phase 2

Descriptive statistics

Table 4 illustrates the demographic breakdown of the participants in Phase 2 ($N = 147$), which included some recurring participants from Phase 1 ($n = 74$).

Correlation of final WQPS items at phase 2

The Pearson correlation matrix in Figure 3 shows individual items of the final 13-item WQPS total score from Phase 1. The matrix again reveals, as in phase 1, that the majority of these items demonstrate moderate to high positive correlation values with each other. Such trends suggest a shared variance between these items, possibly alluding to underlying commonalities that these individual items may be addressing. Moreover, each item exhibits a positive correlation with the total score of the final WQPS, suggesting that they contribute significantly to the composite measure.
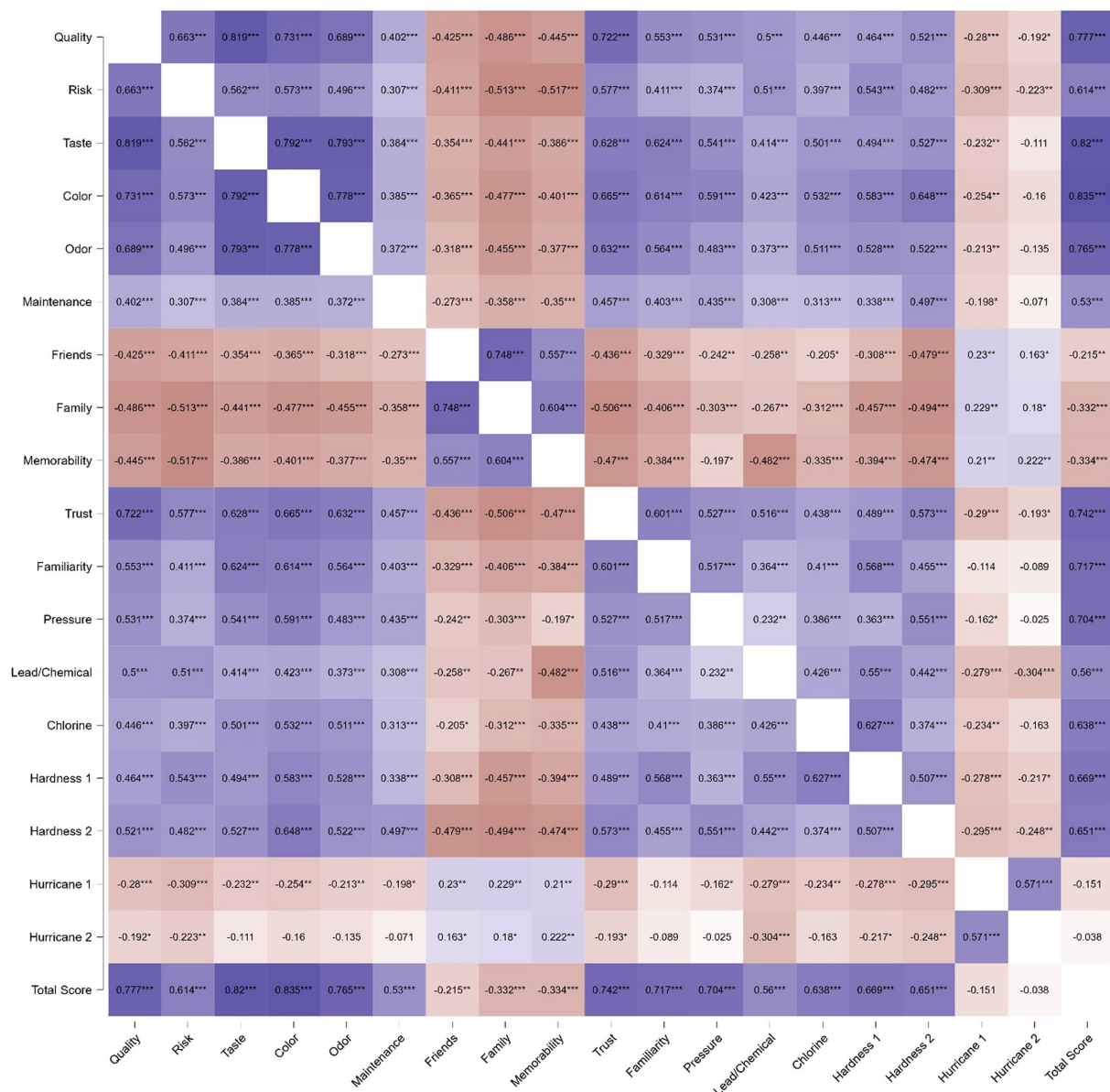
FIGURE 1
Pearson correlation matrix of initial WQPS items in phase 1 (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$).

Confirmatory factor analysis

The CFA restricted loadings exclusively on the identified single factor (Marsh et al., 1998, 2020). The results of the CFA supported the adequacy of this one-factor model. Specifically, the initial fit parameters generated by STATA in the CFA were as follows: $\chi^2(65) = 211.07$ ($p < 0.001$), Root mean squared error of approximation (RMSEA) = 0.134, 90% confidence interval (CI) = [0.114, 0.154]. The Comparative fit index (CFI) and Tucker–Lewis index (TLI) values were 0.83 and 0.80, respectively, while the Standardized root mean squared residual (SRMR) was 0.08.

The model's modification indices hinted that the estimation of error covariances between five item pairs could enhance the model. The

five-item pairs were color-odor, color-lead/chemical, trust-familiarity, lead/chemical-hardness1, and chlorine-hardness1. Error covariances for the five-item pairs were then freely estimated. The final fit indices after modification generated by STATA in the CFA were as follows: $\chi^2(59) = 73.67$ ($p = 0.095$), RMSEA = 0.044, 90% confidence interval (CI) = [0.000, 0.074], indicating a good fit (Hu and Bentler, 1998). The CFI and TLI values were 0.98 and 0.97, respectively, surpassing the recommended 0.95 threshold often cited in research (Kashyap and Singh, 2017; Finch, 2020). The SRMR was 0.054, indicating an acceptable level of model fit way below the threshold of 0.09 (Cho et al., 2020).

Figure 4 shows the distribution curve of the 13-item WQPS at phase 2. Finally, the internal consistency (Cronbach's alpha) of the sample in phase was 0.90 in phase 2.

TABLE 3 Exploratory factor analysis of the water quality perception scale (WQPS) (all loadings >0.3).

WQPS factors and items	No. of Items	Mean	SD	Factor loading	Cronbach's (α)	Eigenvalue
Factor 1: Individual Water Quality Perception	13				0.93	8.89
Tap water is usually of high quality		2.05	1.90	0.79		
There are health risks associated with drinking water in my home from my tap*		2.82	1.98	0.58		
I am happy with the taste of my tap water		1.87	1.99	0.86		
I am happy with the color of my tap water		1.90	2.03	0.87		
I am happy with the smell of my tap water		2.09	1.95	0.85		
The water pipes and taps of my home are clean and well maintained		2.89	1.86	0.49		
I trust my water service company (i.e., AAA/PRASA)		2.26	1.92	0.70		
I am used to my tap water		3.05	1.97	0.70		
I am satisfied with the tap water pressure in my home		2.96	1.89	0.74		
My tap water is contaminated with lead or any chemicals*		3.14	1.85	0.47		
My tap water has too much chlorine*		2.07	1.82	0.65		
My tap water has too much limescale*		3.01	1.96	0.64		
My tap water is too hard*		2.97	1.88	0.58		
Factor 2: External Water Quality Perception	3				0.84	1.57
Some friends told me negative comments regarding my tap water.		1.08	1.83	−0.86		
Some family members told me negative comments regarding my tap water		1.34	2.01	−0.82		
Tap water has caused health problems for me or for someone in my family		0.99	1.64	−0.78		
Factor 3: Hurricane Induced Water Quality Perception	2				0.73	1.35
I am worried about the quality of water and water contamination (e.g., chemicals) during the hurricane season		4.07	1.57	−0.82		
I am worried about the quality of water and water contamination (e.g., chemicals) after the hurricane season		4.35	1.33	−0.88		
Total	18	43.61	16.25	–	0.91	–

*Reverse coded items.

Convergent validity

The Pearson correlation revealed that the WQPS had a correlation of −0.49 ($p < 0.01$) with HWISE, again suggesting convergent validity.

Discussion

The analysis of water quality perceptions occupies a crucial intersection across multiple disciplines, including engineering, geosciences, and social sciences (Weems et al., 2023). This intersectionality highlights the necessity of examining both physical factors, such as the accessibility and sources of drinking water, and intangible factors, notably human water quality experiences and perceptions (Auslander and Langlois, 1993; Heekeren et al., 2008; Hu et al., 2011; Alhassan and Kwakwa, 2013). Accuracy and reliability in measuring these water quality perceptions are paramount. This study makes a significant stride toward refining the measurement of water

quality perceptions, drawing parallels to the methodologies employed in assessing "water insecurity" via the Household Water Insecurity Experiences (HWISE) scale. The Water Quality Perception Scale (WQPS) developed through this research show promise for application in diverse contexts to enhance the understanding of water insecurity and promote uniformity in evaluation of water quality perceptions across different studies.

Further building on the foundational work by Doria et al. (2009), which illuminated the critical influence of sensory experiences—such as taste, color, and odor—on people's perceptions of water quality, this research proposes a set of 13 key items that form the core of the "Individual Water Quality Perception" construct. These findings suggest a unitary construct that revolves around the direct sensory experiences that individuals have with drinking water, suggesting that water quality perceptions are integral components of how water quality is assessed and understood. Moreover, the observed negative correlation between perceived water quality (measured with the
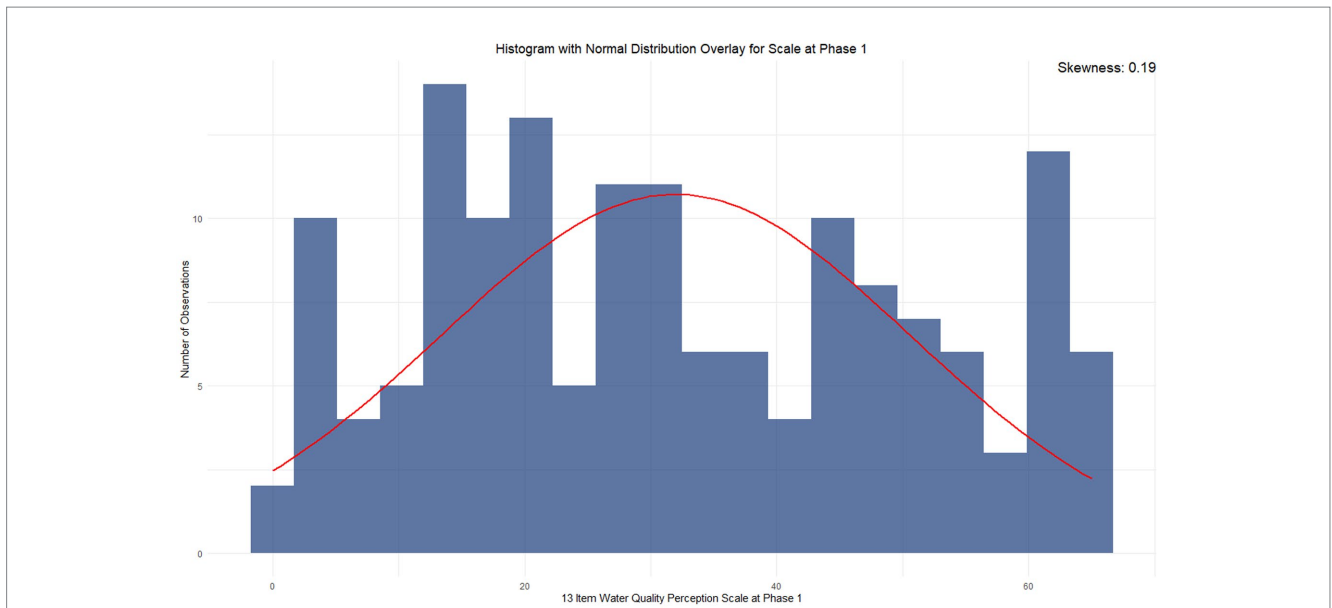
FIGURE 2
Distribution curve of WQPS at phase 1.

TABLE 4 Demographics results of study 2.

Variable	N	Descriptive statistics	Value	%
Age	140	Minimum	22	–
		Mean	58.39	–
		Median	59	–
		Maximum	90	–
Gender	147	Female	124	85%
		Male	23	15%
Education	147	No schooling completed	6	4%
		Elementary school degree	12	8%
		Middle school degree	14	10%
		High school diploma	47	32%
		Bachelor's degree	27	18%
		Associate's degree	30	20%
		Other/missing	11	8%
Race	147	White	81	55%
		Black/African American	16	11%
		Asian	0	0%
		Native Hawaiian/Pacific Islander	0	0%
		American Indian/Alaska Native	1	0%
		Mixed	45	31%
		Other/missing	4	3%

WQPS) and water insecurity (measured with HWISE) suggests that when individuals think highly of their water quality through positive sensory experiences such as clear appearance, pleasant taste, and absence of foul odors, their sense of water security increases. This correlation logically aligns with the expectation that water insecurities tend to diminish when perceptions of water quality are positive.

Moreover, the internal consistency of the WQPS (Cronbach's alpha) for the main scale was 0.93 phase 1 and 0.90 in phase 2. This is similar to previous estimates of the HWISE.

Additional findings warrant comment. First, the distributions illustrated in Figures 2, 4 are that suggesting variance in water quality perceptions was not symmetrically normal with an apparently
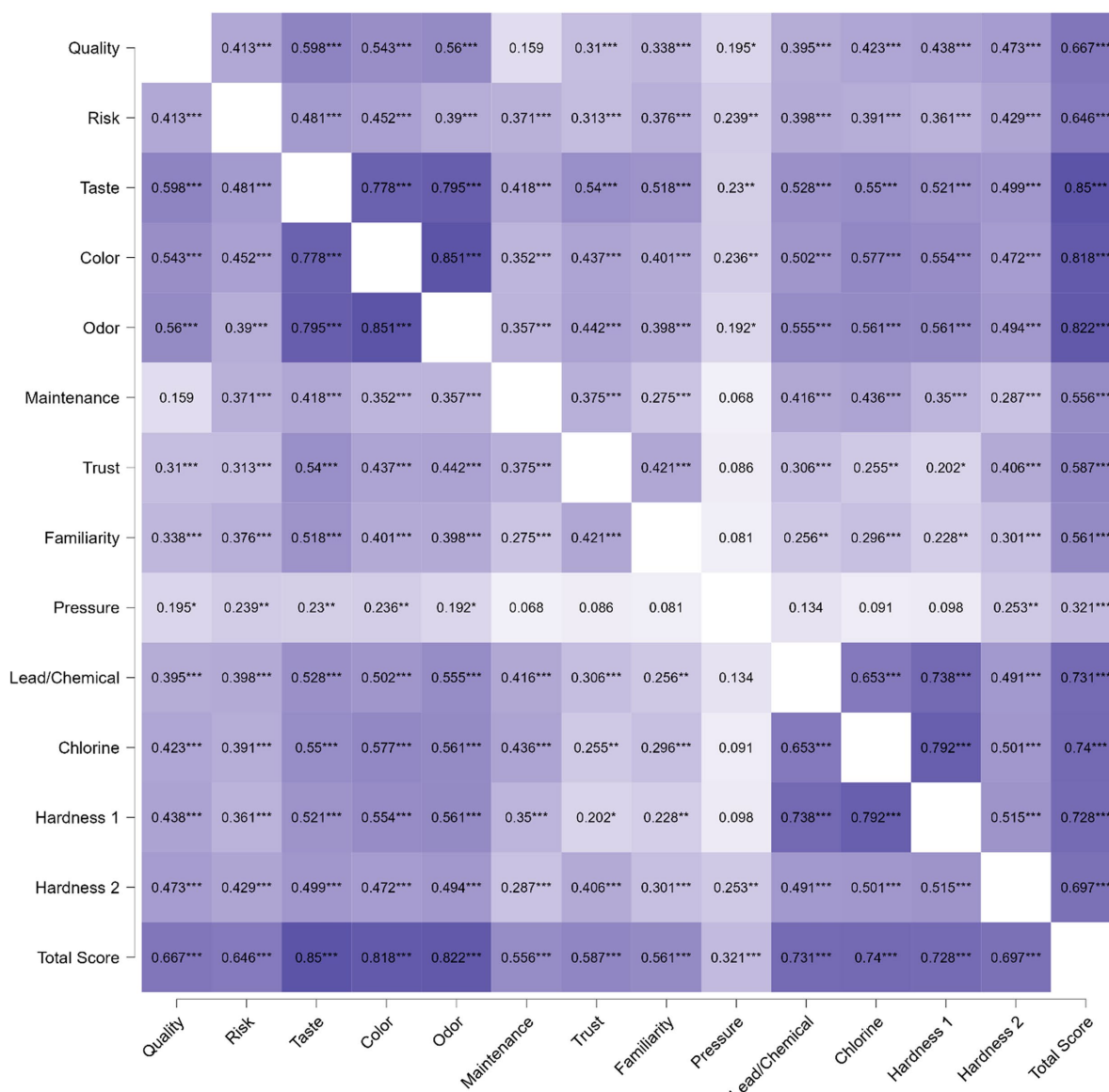
FIGURE 3
Correlation matrix of final WQPS items in phase 2 (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$).

bi-modal distribution in phase 2 (Figure 4) and somewhat multimodality in phase 1 (Figure 2). Future research is needed to examine the distributions of WQPS scores in larger samples. Second, is the Cronbach's alpha of the HWISE which has been reported to be in the 0.84–0.93 range (Young et al., 2019) with internal consistency in this sample at alpha = 0.88 and this study provides additional support for the HWISE's internal consistency and its convergent validity. As noted, previous data suggests the HWISE has equivalence of measurement, predictive, convergent, and discriminant validity (Young et al., 2019). Similar data is needed for the WQPS. Testing measurement invariance across reporters (e.g., sex, age, and language) and contexts is needed to ensure mean score differences that may emerge are not due to the measures functioning differently in different samples. Moreover, we predicted and found that the WQPS scale would be moderately (because water quality is similar but distinct from water insecurity) and negatively correlated with the HWISE

(i.e., more water insecurity is associated with lowered water quality perceptions). How, when, and why exactly water insecurity is related to water quality perceptions is an interesting empirical and theoretical question in need of answers. This may be answered by examining different aspects of water insecurity (Stoler et al., 2023) and their linkages to water quality perceptions. Additional estimates of convergent, discriminant, and predictive validity of the WQPS are needed highlighting the limitations to this initial report.

Study limitations

The present study has several limitations but points to several areas of further study and refinement. The participant sample, chosen for an initial wide distribution of responses, may not fully represent the broader population. This calls for replication and
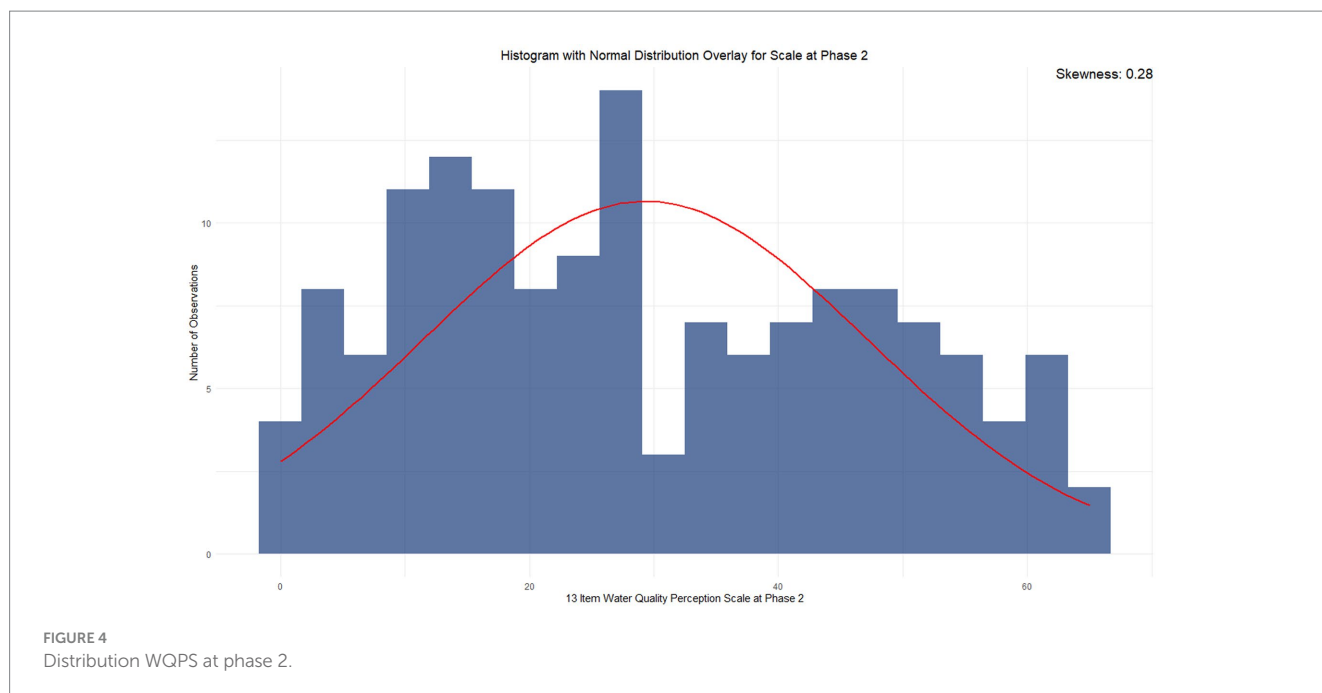
FIGURE 4
Distribution WQPS at phase 2.

refinement of the scale in additional settings or among additional groups. Large-scale studies of broader representative populations on drinking water vulnerabilities are needed. Moreover, the current set of items may not capture all facets of water quality perceptions that a more expansive item set could. Similarly, the question of whether specific terms like 'limescale,' often crucial in water quality discussions, are understood uniformly by all participants, especially considering varying educational and cultural backgrounds. Furthermore, self-reported measures always carry the risk of social desirability bias, where participants might provide responses they believe are expected rather than their true perceptions (Randall and Fernandes, 1991). However, as the scale primarily measures perception, such questioning remains a key method to capture beliefs and attitudes. Research on the linkages between different water compositions within safe drinking limits and quality perceptions may help in the refinement of future items. For instance, incorporating qualitative methods such as in-depth interviews or participatory workshops could offer richer, context-specific understandings of attitudes toward water quality (Lin et al., 2020; Nelson et al., 2023). Additionally, exploring more interdisciplinary research on sensory perception and environmental psychology can inform the development of more sophisticated items for measuring water quality perceptions. Furthermore, existing work on taste sensitivity could be applied in water quality perception research to develop more items (Puputti et al., 2018).

Language dialect differences and the translation of items, particularly for a study potentially involving multi-lingual participants, add another layer of complexity. Recognizing the importance of accurate and culturally sensitive translation, the study was translated into the Puerto Rican dialect of Spanish by one of the authors, a native of Puerto Rico. This approach indicates an understanding of the subtleties involved in translation and the impact of regional dialects on comprehension. Ensuring that participants, especially in regions where this dialect is spoken, have a consistent understanding of each item is crucial for the validity of the findings.

Lastly, while the research identified and focused on the "Individual Water Quality Perception," it is crucial to remember that water quality perceptions are multifaceted, and other external indicators not deeply probed in this study might have significant influence. Future research should aim to address these limitations by developing and further refining the two other indicators related to "External Water Quality Perception" and "Hurricane Induced Water Quality Perception" identified in the study to provide a more comprehensive understanding of the topic.

Conclusion

This study provided initial psychometric data toward measuring and understanding public perception of water quality. Given the ever-growing concerns surrounding water insecurity globally, the WQPS items might be a valuable addition to the studies that aim to understand water crises. By complementing other similar measures, such as the HWISE scale, it may augment assessment of the myriad factors related to water security. Comprehensive, consistent and accurate measurement of water quality are at an important intersection between the engineering, social, policy, and human aspects of water security and sustainability (Weems et al., 2023) and helps answer the call for more comprehensive assessment (Stoler et al., 2023). Public perception is often an enigma for utility providers. Including this module of questions in Housing Surveys (such as the American Housing Survey) could provide data to determine and track the link between the perception of water quality and local-level communication regarding it (Sarkar, 2022), helping utility providers better understand user perceptions.

Periodic deployment of this scale in surveys can furnish utilities with real-time insights into public sentiment. Such proactive gauging of perceptions is pivotal, especially when navigating crises like contamination events or post-disaster scenarios. Addressing areas flagged by the public, whether it is the taste of tap water or concerns

over contamination, allows utilities to prioritize interventions and bolster public trust. For instance, if misgivings about tap water's taste become prominent, utility companies can engage in dual strategies: rectifying potential causes and launching awareness campaigns to educate the public, ensuring that misconceptions are addressed head-on. Public health officials, on the other hand, can also benefit from consistent and accurate assessment. An informed understanding of water quality perceptions can be helpful in devising strategies that nudge the populace from bottled water reliance to increased tap water consumption, addressing both health and environmental concerns.

Lastly, policymakers can utilize consistent and accurate assessments to shape nuanced, community-centric water policies. An in-depth grasp of public sentiment, as facilitated by the scale, ensures that policies resonate with community concerns and aspirations. During crises and disasters, such a tool may be helpful in guiding the formulation and communication of swift, effective response strategies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Iowa State University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TN: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. CP: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. CW: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Methodology, Funding acquisition, Formal analysis, Conceptualization. KI: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition. IG: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation. CR: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1357921/full#supplementary-material

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