



# Gender disparities in water-related knowledge, perceptions, and governance in rural Ghana: insights from a qualitative study augmented by Natural Language Processing

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## ABSTRACT

Gender inequalities remain persistent across water-related activities in labor division and decision-making disparities. Yet, our understanding of these dynamics remains limited to generalized narratives. This study examined gender disparities in water knowledge, perceptions, and governance in rural Ghana, drawing from focus group discussions (FGDs) conducted between January and March 2023. Using both qualitative thematic analysis and Natural Language Processing (NLP), we analyzed FGDs with women (n = 30 FGDs) and men (n = 25 FGDs) covering perceptions, experiences, knowledge, and satisfaction related to drinking water sources and water system governance structures. FGD transcripts were qualitatively analyzed using thematic analysis in Nvivo and coded text was further examined using NLP tools such as sentiment analysis. This approach revealed disparities in experiences with and perspectives on drinking water, in both qualitative and NLP results. Our qualitative results indicate that women had detailed impressions of water quality, closely tracking sensory parameters and health outcomes. In contrast, men tended to adopt a broader perspective, focusing on the local political environment and governance. Furthermore, NLP results suggest women had more negative perceptions of chlorination and a heightened awareness of water treatment than men, indicating active involvement of women in water management could enhance treatment and quality. While both NLP and qualitative results show shared frustrations with governance and a desire to improve water system management, there was no unified demand to increase women's participation. These results highlight nuanced gender perceptions regarding drinking water and reveal a complex set of gendered dynamics. Furthermore, this study introduces an innovative research approach integrating qualitative thematic analysis with NLP tools to enhance the analytical depth and validation of qualitative findings.

## 1. Introduction

Gendered division of water labor, with women and girls bearing the burden of responsibility for household water security, is widely recognized as a systemic social dynamic (UNICEF & WHO, 2023) particularly in rural contexts (Graham et al., 2016). The consequences of this disparity for women and girls include significant workloads and time expenditures (e.g., Geere and Cortobius, 2017), negative health outcomes (e.g., Adams et al., 2022), gender-based violence (e.g., Asaba et al., 2013), and lower school attendance (e.g., Hamlet et al., 2021). Despite women bearing most unpaid water-related labor responsibilities, power imbalances in decision-making concerning water

management often result in limited participation and representation of women in governance bodies or paid positions in the water sector (e.g., Caruso et al., 2023)

The water, sanitation and hygiene (WASH) sector has been slow in addressing these gender inequalities. For example, national water management plans display limited gender considerations (Fauconnier et al., 2018), including Ghana's Water Sector Strategic Development Plan (WSSDP) which references gender as a guiding principle but lacks concrete implementation mechanisms or measurable indicators (Ministry Of Water Resources Works and Housing, 2014). A direct consequence of this oversight is that improvements in water and sanitation systems have been less likely to benefit women and girls

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compared to men, particularly in the context of productive water uses and capacity building (van Wijk-Sijbesma, 1998). Beyond this, not properly addressing gender equality and equity in WASH initiatives may also undermine their very effectiveness. A growing body of evidence suggests that the functionality (e.g., Foster, 2013), sustainability (e.g., Schweitzer, 2013), and financial accountability (e.g., Mommen et al., 2017) of water systems is improved when women are actively and meaningfully engaged. Furthermore, recent work emphasizes the value of incorporating gender-specific perspectives to strengthen water resource management (Packett et al., 2020).

Historically, efforts to foster gender inclusion have focused on increasing women's representation in water management bodies of low- and middle-income countries (LMICs). For example, beginning in the 1980s, sector policies in Tanzania and Malawi included the mandatory participation of women in water committees (van Wijk-Sijbesma, 1998), though implementation of these remains limited (Fauconnier et al., 2018). More recently, multiple countries, including Uganda and Ghana, have adopted gender quota policies that, while de facto increase women's representation, do not necessarily improve active or influential participation and can remain largely tokenistic (Mandara and Niehof, 2017). New frameworks and guidelines have sought to address these concerns in practical ways, including applying gender mainstreaming and gender transformative approaches, as well as relying on new gender equality metrics (e.g., Carrard et al., 2022; MacArthur et al., 2023a,b). Yet, a recent review by Robinson and colleagues (2024) indicated that despite the proliferation of policies and guidelines regarding gender considerations in WASH over the past two decades, projects have not seen a corresponding increase in gender equality outcomes. The authors partially attributed this disconnect to the reliance on reductionist approaches for measuring outcomes in gender equality and equity in WASH programs, including superficial qualitative statements and overly simplistic quantitative metrics. Moreover, they identified these approaches as the primary barriers to achieving meaningful change, calling for more accurate monitoring and evaluation strategies.

Furthermore, recent work suggests that the complexity of the water-gender intersection goes beyond well-established narratives, emphasizing the nuanced nature of gender dynamics within water-related contexts (Dickin and Caretta, 2022). For example, recent UNICEF Multiple Indicator Cluster Surveys have found that men and boys are the main water collectors in a variety of contexts across urban and rural settings, including in Iraq, Jamaica, and Kazakhstan (Geere and Cortobius, 2017), directly challenging long-held assumptions on gendered water-related labor division. In line with these findings, Willetts et al. (2023) argue that effectively addressing and challenging gender inequalities necessitates a more nuanced and context-specific understanding of gender differences. In this sense, understanding the diversity of experiences associated with water across both men and women and acknowledging their specific needs is crucial for addressing gender equality more broadly (Robinson et al., 2024).

These empirical variations in gendered water labor point to deeper questions about how water insecurity is experienced and understood. Recent research highlights that water-related experiences are shaped not only by gender, but also by spatial, cultural, and socio-economic conditions, and are thus not uniform across women or men (Nunbogu et al., 2023). Drawing from this literature and feminist political ecology, we situate our analysis within a framework that explores how gendered water knowledge and perceptions are shaped by everyday experiences, sensory interactions, and governance participation (Sultana, 2011; Jepson et al., 2017; Ballesterio, 2019). This framing situates our study's focus on lived knowledge within broader debates about gendered water governance.

Against this backdrop, our study draws on the lived experiences of rural community members to examine gendered differences in drinking water perspectives, knowledge, and governance. We apply a novel, hybrid methodology that integrates thematic analysis with Natural Language Processing (NLP), an artificial intelligence (AI) field based on

computational linguistics that can enhance our understanding of knowledge and information. While traditional qualitative thematic analyses support the interpretation of complex narratives and the identification of nuanced themes, NLP can facilitate the extraction, categorization, and interpretation of meaningful patterns within textual data, including sentiment (Chowdhury, 2003). Furthermore, NLP methods can be highly scalable and reproducible (Crowston et al., 2012). Yet, while NLP tools have been coupled with qualitative analysis in other fields (e.g., Bardhan et al., 2019; Guetterman et al., 2018), their application to WASH studies remains unexplored. Here, we show how a hybrid qualitative-NLP approach can provide nuanced insights into gender dynamics with practical implications for policy and program implementation. Our results provide a step towards more gender-responsive and efficient implementation of water management programs.

## 2. Methods

### 2.1. Study setting and community selection

We conducted this study from January to March 2023 in Ghana's Ahafo and Bono regions, including 31 rural communities in 11 districts. Data was collected as part of a baseline assessment before implementing an intervention for small community-managed piped water systems to improve water quality testing, water treatment, and water quality knowledge and awareness. The communities selected had to have a community managed water system supplying public standpipes and generating revenues that exceed expenses (REAL-Water, 2023; Bauza et al., 2025).

Most public water systems in rural Ghana are managed at the district level, with district governments owning infrastructure and delegating operations to water and sanitation management teams (WSMTs) composed of community members. WSMTs typically include operational staff managing daily system operations and, in some cases, a water board overseeing finances and decision-making. While WSMTs manage various types of water systems, we specifically focused on communities managing piped water systems supplying standpipes and occasionally household connections. In some cases, communities with mechanized boreholes serving single tap stands were included. We refer to water from these systems throughout the paper as 'piped water'. [Supplementary Information Table S11](#) provides contextual and descriptive data on the communities included.

### 2.2. Data collection

#### 2.2.1. Qualitative data collection

We conducted 55 focus group discussions (FGD) with community members: 30 FGDs with women and 25 FGDs with men. We aimed for one men's FGD and one women's FGD in each community, although this was not possible in 10 communities due to insufficient participants ([Table S11](#)). We included five to seven participants in each FGD, a majority of which used the piped water system in their community. Focus groups were led by trained facilitators, and were an average of 30 min for women and 38 min for men. We excluded community leaders, WSMT members, and water vendors from participating to reduce power dynamics so participants could speak more freely. We included participants who were native to the regions as well as non-native migrants who had settled within the communities (often at least one generation ago) and now spoke the language. Further details about participant recruitment and FGD methods are provided in Section 1.1 of [Supplementary Information](#).

The FGDs focused on experiences with, knowledge of, and satisfaction with drinking water sources, as well as community relationships with the WSMT. While the FGDs were guided by semi-structured protocols, most statements emerged organically within participant-led discussion. Quotes used in the manuscript were selected because they

reflected common themes or represented particularly illustrative perspectives. We obtained written informed consent from all participants before FGDs, which were audio-recorded. We conducted FGDs in the local language, Twi, and later translated and verbatim transcribed them into English for analysis. For confidentiality purposes, community names are anonymized herein. The Institutional Review Board of the Council for Scientific and Industrial Research in Ghana granted ethical approval (RPN 021/CSIR-IRB/2022).

While individual demographic information for FGD participants was not collected, we draw on data from surveys conducted as part of the broader baseline assessment in community households relying on piped water systems, to contextualize the socioeconomic characteristics of each site. These results, along with further methodological survey details, can be found in the [Supplementary Information Table SII](#) and Section 1.2, respectively.

### 2.2.2. Quantitative data collection

We tested samples from public standpipes and private taps (~10 samples per community in total) for *E. coli* (CFU/100 mL), free chlorine residual (FCR), and turbidity, using results to contextualize thematic and NLP findings (see protocols details in Supplementary Information Section 1.3).

We also collected data on chlorination frequency through water operator interviews, categorizing responses to open-ended questions. Roles and management body compositions were also documented during interviews.

## 2.3. Data analysis

### 2.3.1. Thematic analysis

We conducted thematic analysis in Nvivo (Lumivero, Version 10), to analyze narratives concerning water access, quality, and management. Using a mixed deductive and inductive coding approach, we developed a

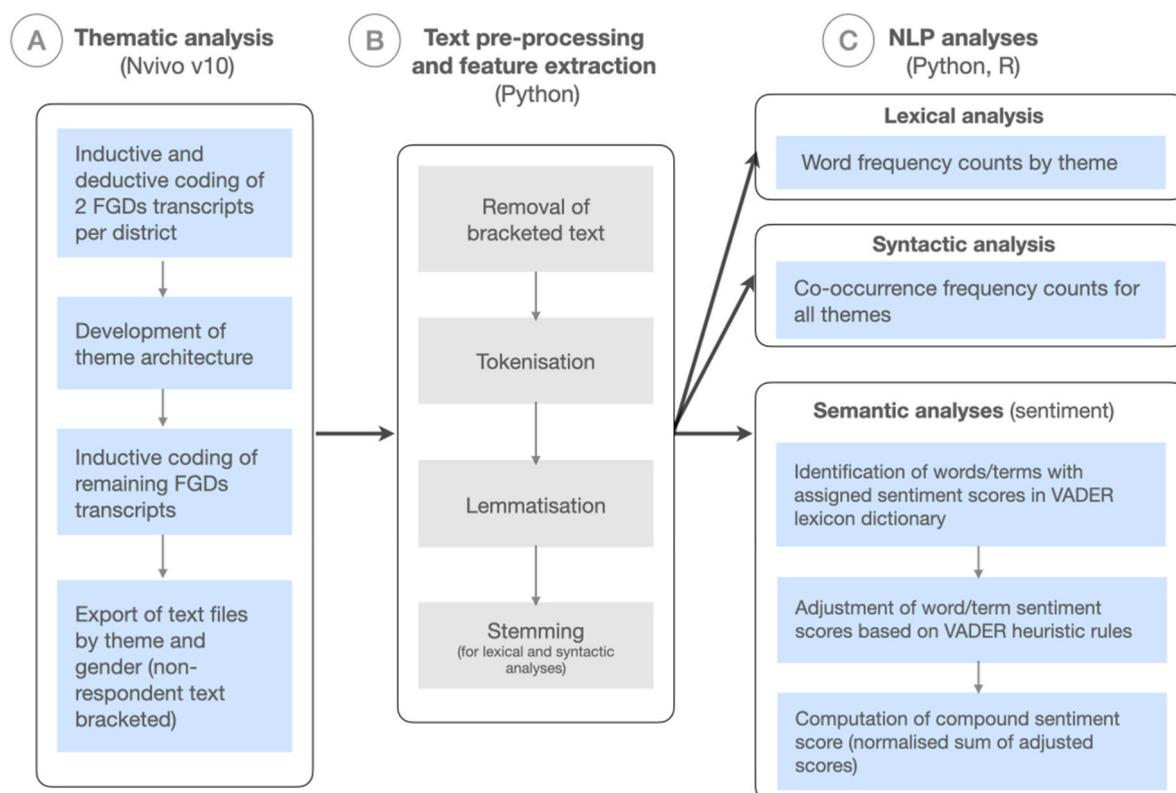
theme architecture using two FGDs per district (see [Supplementary Information Table SI2](#)) and applied it to code all transcripts, summarizing results by gender. For subsequent NLP analyses, the contents of each thematic area were exported as text files for each gender, bracketing content not spoken by participants ([Fig. 1A](#)).

### 2.3.2. Natural Language Processing (NLP) analyses

Our Python-based (v.3.11.4) analytical pipeline included text cleaning, text pre-processing, feature manipulation, and lexical, syntactic, and semantic analyses. This analytical pipeline included an automated removal of the bracketed content of the text files, followed by tokenization and lemmatization, using the NLTK package ([Bird et al., 2009](#)). Stemming was also done for lexical and syntactic level analyses. For selected thematic areas, we further disaggregated text files by community in order to compare sentiment between genders at the intra-community level and as a way of controlling for variability in water system conditions that could impact sentiment values. Supplementary Information Section 1.4 provides detailed definitions of these steps.

We calculated word, sentence, and unique word counts per thematic area by gender. We report frequencies for the top 20 highest frequency words for each theme in the [Supplementary Information Tables SI4-9](#). We also calculated co-occurrence counts of frequently paired words for all themes for each gender in R, and used them to generate semantic networks for the top 30 highest frequency words, as a way to visually compare patterns of discourse (i.e., speech and expression), topic focus, and association.

We measured sentiment using VADER ([Hutto and Gilbert, 2014](#)). In the context of NLP, sentiment scores reflect the degree to which the language being used is positive, negative, or neutral, and are used as a measure of the overall emotional tone of text data. VADER describes both the polarity (i.e., negative or positive) and the intensity of the sentiment and uses a sentiment lexicon comprised of words and phrases,



**Fig. 1.** Analytical workflow depicting the steps and flow of analytical processes divided by thematic analysis (A); text pre-processing and feature extraction (B); and NLP analyses (C). Supplementary Information Section 2.2 presents detailed definitions for technical terms.

and their associated sentiment scores (i.e., valence scores) on a scale of  $-4$  to  $4$ . In order to enhance the accuracy of the sentiment analysis, we expanded the dictionary's lexicon to include recurrent terms in our transcripts, to which we assigned the same valence values as terms conveying similar meaning (e.g., 'typhoid' was assigned the same valence as 'sick'). VADER uses predefined heuristic rules to modify a given word's score when other modulating words are present in the same sentence (e.g., negations, adverbs, contrastive conjunctions). We calculated compound sentiment score by normalizing the sum of these adjusted scores to a scale of  $-1$  to  $1$  using a sigmoid function. We calculated compound scores for a variety of text volumes, including complete theme libraries, quotes, and sentences containing target words (Fig. 1B and C). We note that standardization choices and translation from Twi may have led to some loss of linguistic nuance.

### 3. Results

The qualitative analysis identified six thematic areas: 'Water source landscapes'; 'Level of satisfaction with piped water'; 'Level of satisfaction with non-piped water'; 'Piped water quality'; 'Consumer relationships with water system management bodies'; and 'Composition of water system management entities'. Each of these themes revealed diverse perspectives between men and women as well as within each gender, as summarized in Table 1 and described in detail in the following sections.

NLP analysis also provided insights into how differences between genders are expressed. Semantic networks confirmed differences in discourse between men and women, and provided a more detailed illustration of where these occur with respect to word frequencies and associative patterns (Fig. 2). While some terms were prominent in the discourse of both genders (e.g., 'community', 'problems', 'time', 'money', 'color'), others were more central to women's discourse (e.g., 'pipe', 'smell', 'dirt', 'children') or men's discourse (e.g., 'drink', 'system') (see Supplementary Information Table S13 for detailed frequency counts). Although semantic networks cannot provide a narrative for explaining these differences, they do provide a visual indication that men and women have distinct perspectives and priorities regarding drinking water. Sentiment scores, in turn, indicated wide-ranging sentiments within each gender. In every thematic area, sentiments associated to both genders, ranged from approximately  $-0.9$  to  $0.9$ , spanning close to the full range of possible scores ( $-1$  to  $1$ ) (Table 1).

The following sections examine these differences in depth by thematic area, first describing take-aways from the traditional qualitative analysis, and following with additional insights extracted from NLP analyses.

#### 3.1. Water source landscapes

Both genders broadly acknowledged the crucial role of women in selecting household water sources. This was often mentioned in the context of labor division, with women typically responsible for household chores, including all water-related tasks. Both genders, however, recognized that men are sometimes also involved in fetching water, although this is not common. While not as consistent as views on water source selection responsibilities, both genders often shared the view that men were responsible for paying for water:

*'I think it is the woman. I for instance, use water for cooking, washing and other household chores. So, I know which water is good for what purpose. As for the men, when they get up in the morning, they take their bath, eat and leave for work. They don't know how you came by the water in the household.'* (woman, community Q.1).

*'There is no rule as to who should be in charge of water issues in a household. It all depends on the particular household. The men can fetch water for the household and pay for it just as the women have been doing'* (man, community Q.1).

*'When it comes to the payment with respect to the cost of water for the household use, the man is supposed to pay for it while we the women make all the effort to make sure there is water at home for every member of the household.'* (woman, community W.1).

Cases where the woman is the primary earner or where there are shared household financial responsibilities were also mentioned. In these cases, women were cited as being responsible for payments related to water:

*'When the man does not have money, the woman can support in paying for the water. It is not only the man who has to bear all the responsibilities.'* (man, community T.1).

Participants explained that they relied on a variety of drinking water sources, with piped water being most common and non-piped alternatives such as individual boreholes (mechanized or handpumps), sachet water, and surface water being used when piped water was perceived as inadequate or unavailable. Women's narratives surrounding these alternative sources were often richer and more detailed, including specific information such as the names of the sources, distances, and associated uses:

*'We have another stream called Ekutruku which is also spring water but it does not flow very well just like the Bobini because of where it is located.'* (woman, community W.1).

These narratives tended to express negative views, particularly concerning the availability and quality of surface water sources. Conversely, men's discussions were more focused on the technical and supply challenges of the main piped water system, and they often expressed these concerns in more negative terms than women:

*'The materials [spare parts] of the machines are not readily available and also expensive. That is why it [piped water pump] breaks down frequently.'* (man, community W.1).

Both genders reported accessibility and reliability being the main factors driving source selection. Women, in particular, adapted to accessibility challenges of preferred piped-water sources by relying on multiple non-piped sources, sometimes needing to travel to neighboring communities or further to fetch water. Besides accessibility, women's selection processes were significantly influenced by a variety of factors, including the taste of the water, its suitability for specific purposes, and its price. In contrast, men did not make any references to taste. Finally, both genders cited environmental concerns, with respondents referencing both legal and illegal mining activities as the main culprits of deteriorating ground and surface water quality:

*'The borehole water tastes nice so we prefer it to the piped water.'* (woman, community D.2).

*'If I want to do laundry, I go and fetch the borehole water to wash because the piped water does not lather well with soap.'* (woman, community R.1).

*'We used to drink surface water but the activities of a gold-mining company has destroyed the water.'* (man, community Q.1).

NLP results of this thematic area confirmed that women's narratives were richer and more detailed than men's, and further enhanced the notion that these were particularly negative. Lexical counts produced higher sentence, word, and unique word counts for women than for men, contrasting with the pattern seen in all other thematic areas (Table 1). Furthermore, women had higher frequency counts for terms related to system infrastructure, such as 'tank', 'flow', and 'pump', as well as for some terms related to sources, as shown in Fig. 3 (see Figure S11A and Table S14 for more details). Gender differences also arose when assessing the sentiment of sentences containing specific terms, with women displaying more negative sentiments than men for many of these terms, including 'break' ( $W = -0.66$ ,  $M = -0.33$ ), 'river' ( $W = -0.41$ ,  $M =$

**Table 1**  
Results summary by thematic area.

Thematic Area	Gender	Transcripts	Summary of qualitative results	Summary of qualitative results				Quote highlights (associated sentiment score)	
			Narrative highlights	Sentence count	Word count	Unique word count	Theme compound sentiment <sup>a</sup>		
							Mean positive (Max)	Mean negative (Min)	
Water source landscapes	Men	26	<ul style="list-style-type: none"> <li>Women provided more detailed information about non-piped water sources, especially surface water, including specific details such as names, distance, and associated activities, whereas men often discuss surface water in more general terms.</li> <li>The responsibility for selecting drinking water sources is held primarily by women, who also tend to consider factors such as taste, suitability for specific uses, availability, and price, more often than men.</li> </ul>	612	11621	10000	0.39 (0.82)	-0.34 (-0.91)	<i>'We drink pure water [sachet water] the most. The borehole in this community is easily contaminated in a short time so it is very difficult to drink it after three days of fetching it. Also, the water becomes slippery after three days and also produces some funny odor which makes it very difficult to drink'</i> (female respondent, compound sentiment = -0.07)
	Women	28		655	13048	10968	0.39 (0.91)	-0.35 (-0.90)	
Level of satisfaction with piped water	Men	26	<ul style="list-style-type: none"> <li>Perceptions of water treatment, and corresponding effects on taste and odor, emerged as key points influencing women's satisfaction levels regarding piped water.</li> <li>Both men and women frequently discussed satisfaction levels in reference to functionality, and reliability. Yet, men referenced dissatisfaction with water system management more often than women.</li> </ul>	374	7417	6441	0.45 (0.91)	-0.44 (-0.84)	<i>'We suffer with water supply when there is a power outage. Sometimes we can lack drinking water for four days when there is no power'</i> (female respondent, compound sentiment = -0.86)
	Women	27		272	5380	4622	0.47 (0.98)	-0.42 (-0.91)	
Level of satisfaction with non-piped water	Men	25	<ul style="list-style-type: none"> <li>Men and women expressed both satisfaction and dissatisfaction regarding taste, accessibility, and perceived safety of non-piped water sources, primarily boreholes and sachet water. Surface water was seen as a last resort due to contamination risks.</li> <li>Sachet water was noted to be widely consumed for its perceived convenience and safety, but shared concerns about variable quality, changes in taste after storage were common among both genders.</li> </ul>	192	3575	3122	0.48 (0.86)	-0.40 (-0.83)	<i>'The stream water my father is talking about is our last resort. We only drink that when we have no options, because we share the stream waters with animals like cattle and other animals. We drink it to survive at hard times when no option is available.'</i> (male respondent, compound sentiment = -0.02)
	Women	27		142	2862	2450	0.45 (0.83)	-0.42 (-0.78)	
Water quality of piped water	Men	26	<ul style="list-style-type: none"> <li>Perceptions of water quality were often based on sensory perceptions (smell, color, taste), with women more commonly sharing observations of an unpleasant smell, brownish color, and salty taste.</li> <li>Perceptions of water system storage tank cleanliness and water treatment effectiveness varied among both genders.</li> <li>Both genders shared significant health concerns related to water quality. Women particularly associated piped water with health issues like typhoid and diarrhea.</li> </ul>	224	4837	4212	0.45 (0.87)	-0.45 (-0.90)	<i>'I used to drink the piped water. Then one day I fell ill and went to the clinic. The doctor told me I had typhoid and that I got the typhoid from the water I drink. Since then, I have stopped drinking the piped water. My son also fell ill and was told the same thing. So, now my children and I drink sachet water.'</i> (female respondent, compound sentiment = -0.75)
	Women	28		201	4726	3998	0.44 (0.91)	-0.40 (-0.91)	
Consumer relationships with water	Men	19	<ul style="list-style-type: none"> <li>Both women and men expressed dissatisfaction with the lack of clarity surrounding</li> </ul>	537	11314	9755	0.41 (0.93)	-0.40 (-0.87)	<i>'They misuse the revenue they make from the sale of the water. So, today, if they tell us</i>

(continued on next page)

Table 1 (continued)

Thematic Area	Gender	Transcripts	Summary of qualitative results		Summary of qualitative results				Quote highlights (associated sentiment score)	
			Narrative highlights		Sentence count	Word count	Unique word count	Theme compound sentiment <sup>a</sup>		
								Mean positive (Max)		Mean negative (Min)
system management bodies	Women	21	financial matters and decision-making processes within community management boards. <ul style="list-style-type: none"> <li>Both genders expressed common desires for improved communication from water management authorities, including timely information about the actions taken to treat the water and the water quality itself.</li> </ul>		428	8925	7544	0.44 (0.86)	-0.39 (-0.85)	'to contribute to fix the problems with the piped water system, I will not contribute' (male respondent, compound sentiment = -0.40)
	Men	10	<ul style="list-style-type: none"> <li>Some women expressed concern about the lack of female representation, emphasizing the value of women's experiences and perspectives in water management. Others perceived higher female representation as advantageous due to perceived higher financial reliability.</li> </ul>		174	2986	2699	0.40 (0.85)	-0.36 (-0.73)	
Composition of water system management entities	Women	10	<ul style="list-style-type: none"> <li>Several opinions suggested apathy regarding gender composition of the water board, and a desire to prioritize competence and accountability regardless of gender composition.</li> </ul>		151	2458	2196	0.39 (0.90)	-0.27 (-0.64)	'Once the people on the board are delivering good services, it doesn't matter to me if they are men or women' (male respondent, compound sentiment = 0.45)

<sup>a</sup> We calculated sentence-level compound sentiment by thematic area and gender; and calculated averages for negative sentiment values (<-0.05), and positive values (>0.05).

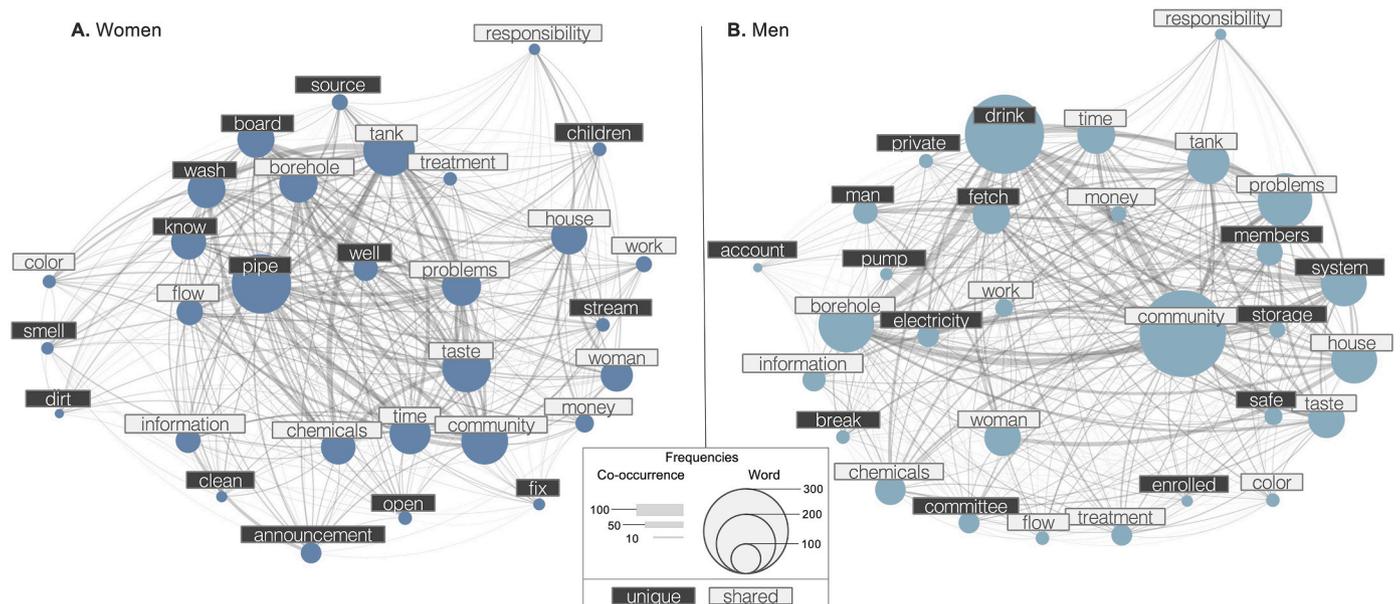
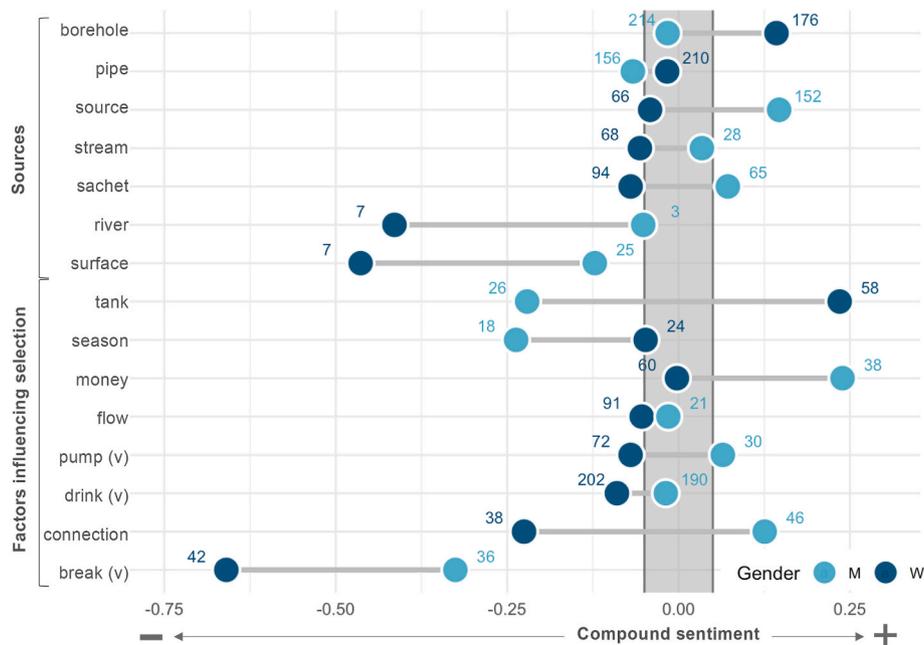


Fig. 2. Semantic networks for women (A) and men (B) for the top 30 highest co-occurrences in each gender. Networks show the relationships between words used by each gender based on their co-occurrence within sentences; node diameter reflects word frequency, and the width of the connecting lines (i.e., edges) reflects co-occurrence frequency. Terms in dark boxes show terms occurring only in one gender, while clear boxes denote terms shared across genders.



**Fig. 3.** Average compound sentiments for sentences containing selected terms for the ‘Water source landscapes’ thematic area. Associated word frequencies are shown next to each sentiment point. Shaded grey area indicates neutral compound sentiment (i.e. between  $> -0.05$  and  $< 0.05$ ). Words were selected to include both high occurrence terms and cover an array of drinking water sources (see SI for complete values). Terms used as verbs are noted with a ‘v’.

+0.05), ‘surface’ (W =  $-0.46$ , M =  $-0.12$ ), and ‘connection’ (W =  $-0.23$ , M =  $+0.13$ ) (Fig. 3 and Figure S11A).

### 3.2. Level of satisfaction with piped water

Both genders expressed mixed levels of satisfaction with piped water. Women more frequently anchored their discussions of satisfaction around water treatment processes, often associating satisfaction/dissatisfaction with the type and frequency of water treatment chemicals and their effect on taste and smell. Some women expressed their desire for greater water treatment to improve water safety, whereas other women disliked how chlorination made water taste or smell. In contrast, men typically did not center their discussions of satisfaction levels with piped water on treatment or chlorination, and their references to taste often noted women as the primary bearers of complaints:

*‘If the water board water could be treated, we would have no problem drinking it. We don’t drink it only because it is not treated. There is no other reason. If we drink it as it is now, we could get sick.’* (woman, community P.1)

*‘I don’t know what actions they take to make the water safe. What I know is that sometimes the water becomes very whitish and unpleasant to drink and tastes like parazone [bleach]’* (woman, community J.1)

*‘When the women go and fetch the water, they usually complain that it does not taste good’* (man, community K.1).

Poor reliability of piped water also emerged as a common source of dissatisfaction across genders, with men more frequently highlighting issues with water availability and management of the water system, sometimes due to power outages and seasonality or maintenance and communication:

*‘The workers there [WSMT] sometimes deliberately close the pipes. They can do this for several days and people will be struggling for water.’* (man, community J.1).

*‘The water board water tastes very good but we don’t get it all the time because of the power failure or light off problems we have in this community’* (man, community O.1)

*‘One of our major problems with drinking water is that we are not able to get enough water during the dry season’* (man, community A.2)

NLP analyses of this thematic area reinforced qualitative results indicating that women’s satisfaction with piped water was closely associated with water treatment, while men’s was more associated with reliability. Across all discussions of piped water satisfaction levels, men had a higher sentence, word, and unique word counts than women (Table 1), yet, more nuanced differences emerged for frequency counts of specific words (Figure S11B, Table S15). Notably, women cited chemicals (including the terms ‘chlorine’ and ‘medicine’ [a local term for chlorine]) over three times more frequently than men. Conversely, men mentioned terms associated with functionality much more often than women (e.g., ‘pipe’, and ‘electricity’).

Results from sentiment analyses further echoed the wide range of satisfaction levels observed in qualitative results. Average compound sentiment scores yielded some of the most negative values obtained by thematic area (M =  $-0.44$ , W =  $-0.42$ ; Table 1), while they also produced the most positive average sentiment for women ( $+0.47$ ). Sentiment associated with a few specific terms (e.g., ‘flow’, ‘system’, and ‘borehole’) reflected marked gender differences (Figure S11B and Table S15). However, the majority of high frequency words showed very small sentiment differences between genders. This includes the term ‘taste’, which notably yielded positive sentiment values for both men ( $+0.25$ ) and women ( $+0.26$ ).

### 3.3. Level of satisfaction with non-piped water

Taste, accessibility, and perceived safety were predominant themes across both men’s and women’s discussions of non-piped water. Boreholes and sachet water were the most common non-piped water sources discussed, while most references to surface water sources described them as unsuitable for drinking and only used when access to other sources was limited:

*‘The other day I saw some people drinking some surface water and I was so worried. Farmers use weedicides close to the surface water and rain water washes the weedicides into the water. But because there was no*

water around, the person was compelled to drink it.' (man, community R.1).

Several men noted they preferred boreholes owned by informal water providers over piped water because of the taste and water temperature, but both genders doubted the safety of privately owned water sources due to a lack of oversight and maintenance:

*'The water from the borehole is usually cool hence very nice to drink. But the water from the water board is mostly warm. So, I prefer the borehole water to the piped water from the water board.'* (man, community J.1).

*'As for the water, the government one is better than the ones owned by individuals. The individual ones don't care about safety. They can decide to treat it or not to treat it and no one can question them.'* (man, community N.1).

Sachet water emerged as a commonly consumed option for both men and women due to its perceived convenience and safety, though several participants were dissatisfied with its high costs. Men referenced sachet water more often than women and shared more frequent concerns about its variable quality, including changes in sachet water after storage:

*'There is a problem with the sachet water. When [we] buy it and leave it for about 3 days, its smell changes and this can cause us to fall sick.'* (man, community D.1).

*'Due to recent increases in prices, sachet water is now very expensive. But we are still forced to buy it because we have no alternative.'* (woman, community Q.1).

NLP analyses of this thematic area reinforced qualitative findings suggesting that sachet water was recurrently referenced by men. However, NLP analysis also demonstrated large discrepancies in sentiment between men and women, indicating a greater ability to discern gendered perceptions. Men's discussions had higher lexical counts than women's, and the highest average positive sentiment values among all themes (+0.48; Table 1). Frequency counts of specific terms yielded large differences between men and women for several terms, such as 'sachet' (M = 88, W = 50) and 'taste' (M = 69, W = 108). Moreover, several sentiment values associated with individual words showed large discrepancies between men and women, including 'surface' (M = -0.16, W = +0.24), 'brand' (M = -0.30, W = -0.03), and 'smell' (M = -0.61, W = -0.25). Figure S11C and Table S16 show detailed results.

### 3.4. Piped water quality

When describing perceptions of water quality, both genders often referenced sensory parameters (smell, taste, appearance), chlorination, and tank maintenance, but these aspects were more recurrent in women's discussions. Descriptions of "unpleasant smell," "brownish color," and "salty taste", indicating a perceived poor water quality, were common across both genders. However, within individual communities, men and women often had different perceptions of water quality, such as cleanliness of water storage tanks and the effectiveness of water treatment measures. While men more often reported the water being "treated with chemicals", and observed water managers "periodically cleaning the water tank", women more often reported the water "not treated at all" and the storage tank "never been washed before".

Men and women both expressed significant health concerns associated with water quality, including instances of individuals falling ill after drinking piped water, describing skin itching, eye problems, stomach aches, and diarrhea, amongst others. However, when examining health concerns within a given community, notable differences arose between genders. For example, while the women in community J.1 reported typhoid as a major concern, noting *'The piped water gives us typhoid. A lot of people in the community have typhoid and the doctors say it is caused by the piped water.'*, men of the same community only reported concerns about smell and taste.

NLP results from this thematic area enhanced qualitative findings suggesting women discussed sensory parameters and treatment related terms more often than men. Frequency counts for terms such as smell (W = 19, M = 9), taste (W = 39, M = 23), color (W = 47, M = 29), dirt (W = 27, M = 8), chlorine (W = 69, M = 47), and tank (W = 85, M = 66) were higher among women than men (Figure S11D, Table S17), while men had higher overall lexical counts across the entire thematic area than women (Table 1).

Sentiment analysis also yielded notable intra-community differences between men and women (Fig. 2). From 21 community pairs, 10 showed more negative sentiments among women and 5 showed more negative sentiments among men (only 6 communities showed similar sentiments between both genders) (Fig. 4). Yet, extreme sentiments (positive or negative) were not associated with objective water quality parameters such as turbidity, chlorine concentration, or microbial contamination (Fig. 4), suggesting that sentiment is not associated with actual water quality. Similarly, there was no apparent correlation between sentiment values and chlorination frequency as reported by water system operators (Fig. 4). There was also no correlation between sentiment and female representation in water governance bodies. Notably, communities that did not have a community water board tended to have the largest sentiment differences between genders (Fig. 4). Moreover, sentiment values did not appear to correlate with community-level wealth, income, or education, based on household survey data.

### 3.5. Consumer relationships with water management entities

Respondents of both genders expressed concerns over the lack of transparency and accountability of WSMTs, and a shared desire for better communication. Men and women expressed dissatisfaction with the lack of clarity surrounding financial matters and decision-making processes within community management boards, and were disappointed by increasing tariffs and discrepancies in billing. Women discussed a need for more regular announcements and updates about service interruptions, while both genders described a desire to receive more information from WSMTs regarding water treatment and safety, emphasizing the need for periodic updates to maintain community confidence:

*'What we want them [the water board] to understand is that the water system is not their personal property. So, they need to be accountable to the people'* (man, community Q.1)

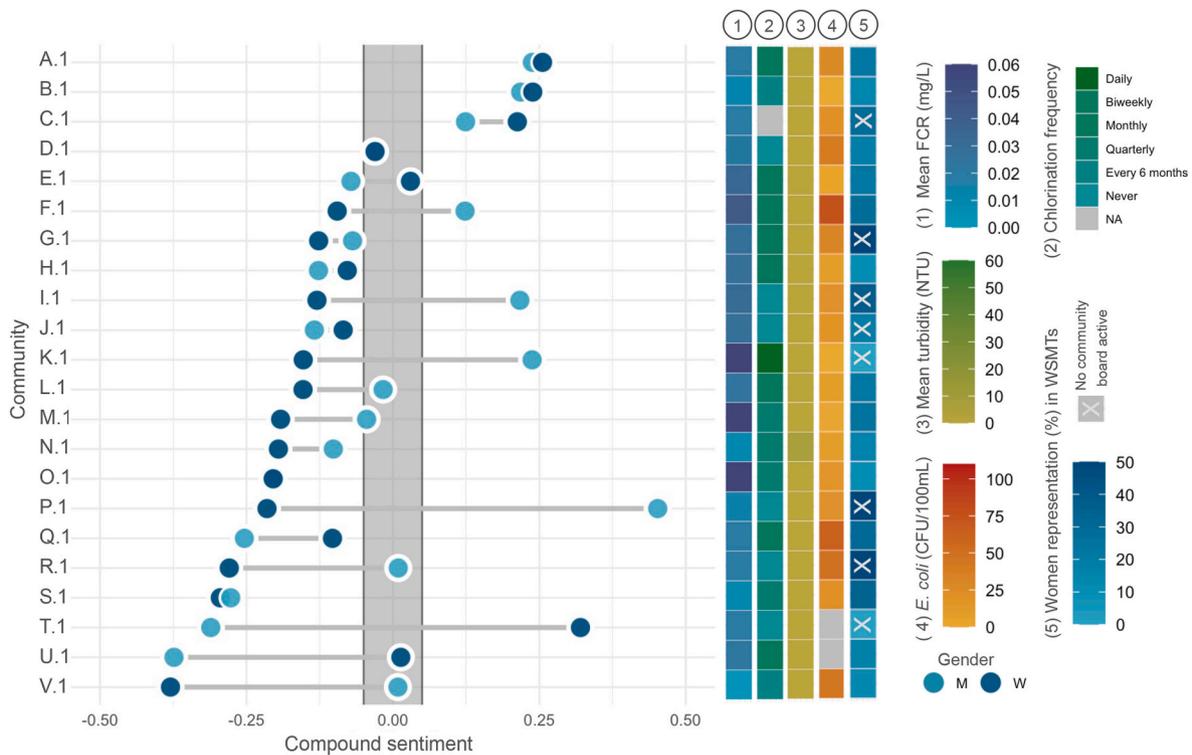
*'The information we want to hear from them is that, if, for instance, they want to wash the tank and treat the water, the community should be informed so that people can store water. Also, if they decide to treat the water with chemicals, then they should let us know how long it will take for the smell of the chemical to leave the water before we go to fetch it.'* (woman, community Q.1)

WSMT's handling of water system maintenance and repairs was also a key discussion point among respondents, particularly emphasized by women participants. Both men and women acknowledged the responsiveness of water management teams to address infrastructure repairs, noting WSMTs take swift action to resolve problems in many communities. Yet, women's perspectives reflect more negative views on the overall work of the WSMT, including references to delays in repairs, as well as the lack of treatment and tank maintenance:

*'... they should be able to wash the tank every two or three months but with ours it has been a long time since they last washed the tank.'* (woman, community N.1).

*'When you complain to them they always tell you there is no money to repair the pipe but we always pay for the water.'* (woman, community S.1)

NLP results from this thematic area supported qualitative findings suggesting women discussed infrastructure repairs more often than men,



**Fig. 4.** Compound sentiments for the ‘Water quality’ thematic area, disaggregated by community and gender. Only communities for which both genders were interviewed are shown. Shaded grey area indicates neutral compound sentiment (i.e. between  $> -0.05$  and  $< 0.05$ ). Water quality parameters sampled from public standpipes and private taps are shown for context for mean free chlorine residual (FCR, 1); reported chlorination frequency (2); mean turbidity (3); mean *E. coli* CFU/100 mL (4); women’s representation in WSMTs and whether they have a community water board (5). Communities ‘D.1’ and ‘O.1’ show an overlap on sentiment values for men and women.

but also highlighted women’s greater attention to communication, which was not identified in the qualitative findings. Women used terms related to breaks and repairs of the water system at higher frequencies such as ‘break’ ( $W = 64, M = 37$ ), as well as terms related to communication with the community such as ‘announcement’ ( $W = 276, M = 186$ ) and ‘meeting’ ( $W = 65, M = 36$ ; Fig. 5A and Table S18). Contrastingly, men more frequently discussed terms related to management (Fig. 5A and SI.1E, Table S18) and had higher lexical counts across the entire thematic area (Table 1).

Sentiment analyses on this thematic area revealed interesting nuances in gender differences. References to the work of the WSMTs yielded more positive sentiments among men (+0.21) than women (-0.21; Table S18) (Fig. 5A). This was also the case for references to systems ( $W = -0.35, M = -0.08$ ), chemicals ( $W = -0.25, M = -0.09$ ), and fetching ( $W = -0.14, M = +0.29$ ), among others (Fig. 5A). However, when disaggregated by community, sentiments about management entities were much more similar between genders (Fig. 5B). This was particularly true when the water system had an active board and higher representation of women in the WSMT (Fig. 5B). Similar to the ‘Piped water quality’ thematic area, we did not find a relationship between sentiment values and education, wealth or income data coming from household surveys.

### 3.6. Composition of water management entities

Perspectives on the composition of the community board revealed a variety of viewpoints regarding the selection process, gender representation, and the suitability of women for certain roles within the board. The selection process for water board members appeared to vary across communities, with some relying on community leaders (e.g., chiefs and elders, or the district assembly) to appoint board members while others held elections. Women’s representation was lower among water system

operational staff ( $<1:3$  in 82 %) compared to water boards ( $<1:3$  in 62 %) (Table S11).

Despite gender imbalances, neither women nor men uniformly called for greater female representation in WSMTs, and when they did, it was typically in the later stages of the topic discussion and after the FGD increased their awareness of gender disparities. Initial views often included questions on the suitability of women for certain technical tasks, as well as indifference to the gender composition of the board, prioritizing effective service delivery and accountability over gender balance:

*‘What I am concerned about is that there should be reliable supply of water. When I wake up in the morning and open my tap, there should be water flowing from it. Then at the end of the month when they bring the bill, I also go and pay. That is all I care about. And not how many women there are on the board.’* (woman, community I.1).

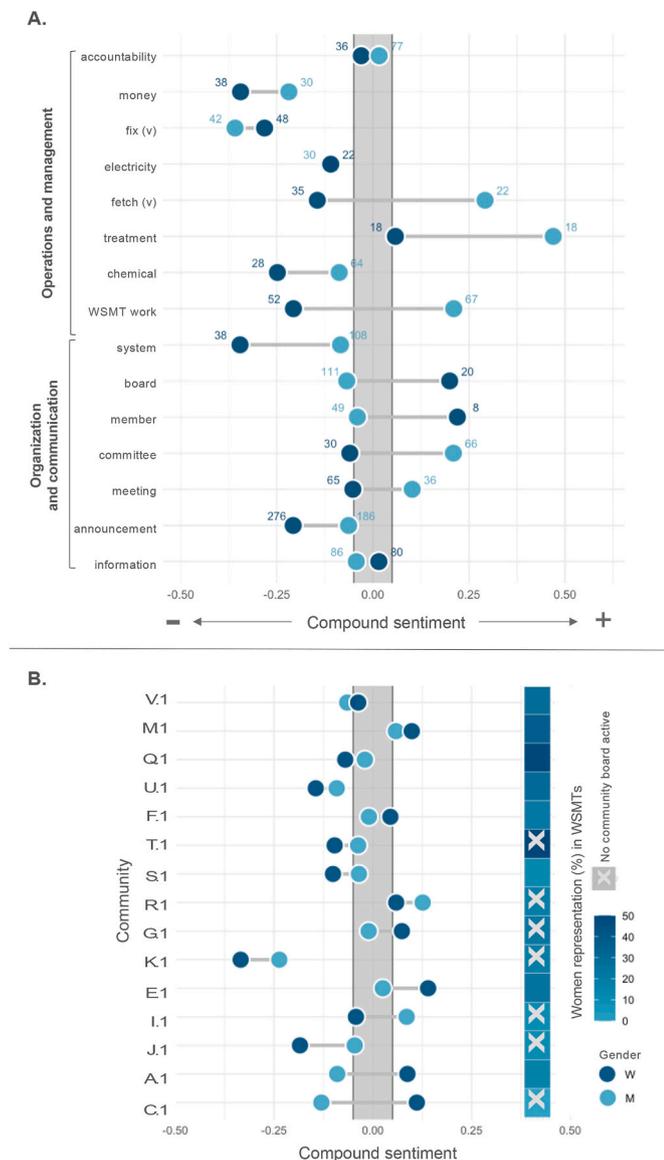
However, later points of the discussion often included women expressing concern regarding the lack of female representation on the water board, highlighting the added value of experiences and perspectives women can provide:

*‘Women understand issues of water better. So, we’ll be happy if about 2 or 3 more women are added to the water board.’* (woman, community R.1).

Some men also suggested women’s involvement could improve financial accountability issues:

*‘If women were to be included in the board, there would be transparency. If something went wrong, they would come out to say it. They will not support a coverup of any issue.’* (man, community S.1).

NLP results emerging from this thematic area reinforced qualitative results suggesting discussions on WSMT membership were often more



**Fig. 5.** Compound sentiments for the thematic area ‘Consumer relationships with board water management bodies’ obtained from sentences containing selected terms (A). Terms were chosen to include both high occurrence rate terms as well as to cover a variety of terms associated with governance and communication, and word frequencies are shown next to each sentiment point. Terms used as verbs are noted with a ‘v’. Compound sentiments from these codes disaggregated by community (B). Communities are arranged from higher to lower gendered sentiment differences and contextualized with the percentage of women’s representation in WSMTs and whether they have a community water board. Shaded grey area indicates neutral compound sentiment (i.e. between  $> -0.05$  and  $< 0.05$ ).

neutral than for other thematic areas, with less marked differences between men and women. While lexical counts were found to be higher for men compared to women, these were not as pronounced as what was observed for other areas (see Table 1). Additionally, sentiment analysis yielded the most neutral average negative sentiment scores of all thematic areas ( $W = -0.27$ ,  $M = -0.36$ ), and sentiment scores associated with target words were remarkably similar for men and women, with the exception of the terms ‘job’ ( $M = +0.51$ ,  $W = -0.21$ ) and ‘training’ ( $M = +0.37$ ,  $W = -0.08$ ; see Figure S11F and Table S19 for complete results). Furthermore, when sentiment was disaggregated by community, differences between men and women remained small. Notably, community-level sentiments did not appear to reflect actual women’s

representation on WSMTs (Supplementary Information Section 2, Figure S12), nor to have a correlation with community-level income, education, or wealth levels, derived from household survey data.

#### 4. Discussion

This study applied a novel, hybrid qualitative-AI methodology to dissect gender asymmetries in water knowledge, perceptions, and governance in rural Ghana. By integrating thematic analysis with NLP techniques, we found that water management in rural Ghana is highly gendered, both in terms of roles and sentiments. Our results indicate that men and women have distinct experiences, perceptions, and knowledge regarding drinking water, which are reflected in the way they communicate. While our results suggest that gender dynamics are variable and that traditional gender-water narratives might not be sufficient in accommodating this diversity, women were generally the primary water source selectors and, as such, encountered daily accessibility challenges that demand adaptive strategies. As a consequence, they possessed nuanced practical knowledge of local water landscapes. Moreover, women exhibited a granular understanding of water quality, closely tracking sensory parameters and health outcomes. In particular, women demonstrated a heightened awareness and discussion of chlorination-related impacts, including on taste and smell, compared to men, suggesting a gender disparity in the perception and communication of water treatment practices. Similarly, women consistently raised issues concerning maintenance activities, including tank cleaning, across thematic areas and contexts. Conversely, men shared a more generalist perspective, often focusing on the management of water systems and discussing broader governance issues.

Our results further indicated that women possess a more negative and acute perception of water treatment than men. While the negative impact of chlorination on consumer preferences has been documented across several contexts (Crider et al., 2018; Jeuland et al., 2016), gender differences have not been extensively reported. Our results have two implications. First, they suggest that women may be more sensitive to changes in water taste due to chlorination. Therefore, women-targeted communication and sensitization must accompany increases in chlorination to prevent women from switching to a different source due to taste and smell concerns. This issue has practical implications for the water quality intervention we are implementing in this study area (REAL-Water, 2023). Notably, we initially designed community engagement activities related to water quality and treatment using local radio programs with a primarily male audience, intending to target the primary household decision-maker. However, our results indicate that women typically make household decisions on drinking water source selection and are also more sensitive than men to changes in the smell or taste of water resulting from chlorination. These findings emphasize the importance of engaging women in sensitization and community engagement activities and the need for different messaging strategies for men and women within communities.

A second implication is that women’s active participation in water management and governance bodies could improve water treatment and quality. However, while other studies found correlations between women’s participation and improved functionality (e.g., Foster, 2013), sustainability (e.g., Schweitzer, 2013) and accountability (e.g., Mommen et al., 2017) of water systems, our results did not show a clear relation between women’s representation in water governance bodies and water quality parameters. Possible explanations for the lack of discernible relationships include that women’s representation was low across all systems, particularly across management roles, with women mostly focused on financial and secretarial positions. This is in line with previous research suggesting that, while mandatory gender quotas were introduced in Ghana through the Affirmative Action Policy in 2006 to promote women’s representation at the District Assembly level, these have had varying levels of enforcement and success (Svahn, 2011). Furthermore, this is in line with a growing body of research that suggests

gender composition metrics are a proxy that does not necessarily translate to or reflect decision-making power or active participation (e.g., [Mandara and Niehof, 2017](#)).

Additionally, we found that sentiment values were not associated to objective water quality parameters, reinforcing the notion that sensory perception is uneven ([Spackman and Burlingame, 2018](#)), and that perceptions of water quality are influenced by a variety of other factors. These may include differences in trust, communication, and lived experiences concerning water systems ([Sultana, 2011](#)), and highlight the need to better understand how consumer sensory knowledge is formed, valued, and integrated into rural water management.

We also found that while community members shared a sentiment of frustration with management entities regarding their governance, accountability, and communication practices, as well as a collective desire for improved management, there was no homogenous demand to increase women's participation. This resonates with existing literature in emphasizing how women's expertise and knowledge related to water security are often undervalued (including by themselves) and underused in management organizations (e.g., [MacArthur et al., 2023b](#)). Nonetheless, the attitude changes regarding women's involvement in management entities during the progression of our FGDs suggest that active discussions can influence the value assigned to women's perspectives, and showcase a path forward to fostering meaningful inclusion. Other recommendations for increasing women's active representation in water governance bodies include raising awareness of the value of women's knowledge and experience ([Mandara and Niehof, 2017](#)), and sharing the positive outcomes when female leadership is present ([Mommen et al., 2017](#)).

While our study did not aim to assess correlations between water-related perceptions and demographic characteristics, and we did not collect detailed information on FGD participants, we supplemented the analysis with household survey data from the same communities to provide broader socioeconomic context. These data suggest that community-level differences in education, income, or household wealth, were not clearly associated with the gendered sentiment patterns observed in the FGDs. However, we acknowledge the limitation of relying on community-level metrics, and recognize that socioeconomic factors could influence individual experiences and, in turn, perceptions and knowledge. For example, women with formal education, who may be more likely to hold leadership roles, might not have the same water-related knowledge as women with lived, sensory-based experience. Although our current data does not allow us to fully explore these nuances, our findings underscore the need for more granular, intersectional approaches in future work to better capture the diverse ways in which gender intersects with other social positions to shape water-related knowledge, roles, and governance. In this regard, the integration of NLP tools may offer an opportunity to identify subtle patterns of differentiation, even when explicit demographic disaggregation is unavailable.

Building on this potential, our study presents a novel way of complementing qualitative thematic analyses with NLP tools. We showed that NLP can both validate traditional qualitative analyses and enhance analytical depth, sometimes providing new insights not apparent in the thematic analysis. Moreover, NLP tools also quantified gender disparities at the community level, offering a richer interpretive framework for qualitative studies. The use of NLP tools and metrics presented in this study can also support monitoring and evaluation of implementation programs, providing scalable and standardized impact tracking through qualitative data. For example, impact evaluation techniques could include analysis of sentiment scores longitudinally or between trial arms, to measure shifts in community sentiment and satisfaction. In the context of gender equality and equity in WASH, NLP tools can provide a quantitative alternative to the reductionist approaches commonly used to report outcomes, such as generalist qualitative observations and overly simplified quantitative metrics, which have been identified as one of the major barriers for meaningful change ([Robinson et al., 2024](#)).

However, it is essential to note that the NLP tools used here are limited in their ability to interpret context and sentiment, and consideration should be given to how their results are evaluated. The technicality underlying NLP methods also represents a significant barrier for more generalized use, although the development of automated tools might make them more accessible. In this sense, further developing and refining NLP tools to cater to specific analytical needs in the context of gender equity and equality is crucial. This includes creating culturally relevant sentiment lexicons and enhancing the accuracy and reliability of analyses. The findings presented here are also intrinsically context-specific and may not be generalizable to other settings. While we relied on translated verbatim transcripts and employed the same native-speaker transcribers for both men's and women's FGDs to maintain consistency, it is important to acknowledge the potential for translation bias, as all nuances might not be fully captured. Finally, our analysis relied on FGDs, which might not highlight all underlying individual perspectives ([Kitzinger, 1994](#)).

## 5. Conclusions

This study highlights significant gender disparities in water-related knowledge, perceptions, and governance in rural Ghana. Key findings indicate that women have detailed and practical knowledge of water sources, quality, and treatment practices. Yet, this nuanced understanding contrasts with their overall low representation in water management bodies. While this study underscores the critical need for women's active participation in water management and governance bodies to improve water treatment and quality, a strong demand to improve this representation is notably absent. Nevertheless, engaging in critical dialogues that leverage women's unique perspectives can lead to the reappraisal of women's inclusion and participation.

The integration of NLP tools with qualitative thematic analysis provided a richer analytical framework, revealing subtle gender dynamics and enhancing the robustness and validity of the qualitative findings. While this hybrid approach to qualitative analyses can be strategically used to enhance analytical resolution and provide a quantitative backdrop, its use and limitations should be carefully considered. Nevertheless, this novel integration suggests that NLP tools could play an important role in the monitoring and evaluation of WASH programs, including gender equity and equality targets, offering new ways to quantify qualitative insights and monitor program impact over time.

Finally, these findings imply that interventions should be responsive to specific gender dynamics of the local context, and that policy frameworks should consider the existing, and often complex, gender dynamics in order to foster genuine inclusivity in governing bodies and decision-making processes.

## CRedit authorship contribution statement

**Lucía Nadal:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Caroline Delaire:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Bashiru Yachori:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation. **Ranjiv Khush:** Writing – review & editing, Funding acquisition. **Valerie Bauza:** Writing – original draft, Supervision, Project administration, Methodology, Conceptualization, Writing – review & editing.

## Ethics statement

This study received ethical approval from the Institutional Review Board of the Council for Scientific and Industrial Research in Ghana (Approval Number: RPN 021/CSIR-IRB/2022). All participants provided informed consent prior to their participation in the study.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.socscimed.2025.118338>.

## Data statement

All relevant data supporting the findings of this study are included within the manuscript and its supplementary materials.

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