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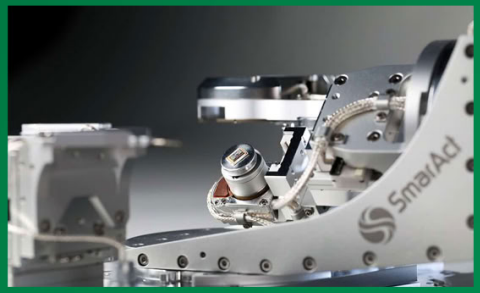
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TOPICAL REVIEW

How intermittent piped water supplies impact households and coping strategies: a systematic review

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Supplementary material for this article is available online

Abstract

More than a billion people globally use a piped water system that is an intermittent water supply (IWS), where water is often unavailable from the network. Previous reviews have summarized relationships between IWS, water quality, human health risks, and coping costs. Yet, beyond these documented impacts, IWS bears additional—often invisible—burdens on users comprising both financial and non-financial costs and social and health burdens. We conducted a systematic review to document these burdens by searching databases for publications that described human impacts of IWS and coping or adaptive management strategies at the household or individual level. We used a novel codebook of coping strategies and adaptive management to synthesize 140 studies meeting our inclusion criteria conducted in 36 countries between 1994–2023. The most frequently reported impacts were increased household spending, poor water quality, time lost managing water, livelihood disruptions, and hygiene/sanitation interruptions. We also found evidence of links between IWS and respiratory infections, vector-borne diseases, dietary changes, physical strain and injuries, dehydration, sleep disruption, psychosocial stress, and interpersonal violence. The most common coping strategies were related to water storage, purchasing, and acquisition costs. Unpredictable IWS was most commonly linked to a small set of household impacts. This review demonstrates that the impacts of IWS on households are more diverse than previously synthesized and highlights the importance of interdisciplinary work to support sustainable solutions that mitigate adverse household impacts of IWS systems.

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1. Introduction

In many parts of the world, particularly in low- and middle-income countries, households and communities connected to piped water networks experience an intermittent water supply (IWS), meaning water is unavailable for significant periods of time. IWS encompasses a wide range of supply practices that includes the provision of water for specific times during the day or week, as well as supplies that can be inconsistent and unpredictable [1]. This creates challenges for households to plan their water usage and meet their needs effectively. The number of IWS users is estimated to be between 1 billion [2] and 1.3 billion people worldwide [3], with exact figures limited by inconsistent terminology to describe IWS practices (e.g. unreliable, interrupted) and limited data.

IWS is indicative of more pervasive environmental influences and rationing of economic, social, and technical inputs [4–6]. Some systems may lack the necessary infrastructure and support to provide continuous water supply. In some cases, IWS systems deliberately ration water when water resources are insufficient for the population served [3]. As the world enters what the United Nations describes as a new era of 'global water bankruptcy' [7], IWS will likely become more common as water demand from rapid population growth and urbanization outstrips the capacity of existing, and often inadequately maintained, water supply systems. Additionally, poor water resource management and changes in precipitation and increased frequency of droughts (among other extreme weather events) threaten supplies and water availability [8–12].

Several systematic and narrative reviews have summarized the multifaceted burdens borne by IWS users. Ercumen *et al* [13] reviewed the impacts of water system interruptions on endemic gastrointestinal illness—perhaps the first review to focus on health impacts. Other reviews have documented a wider set of social and mental health impacts associated with different forms of intermittency, including the social costs of disruption of daily routines, missing social events or enduring conflict between members in the household, perceived ethnic discrimination by the government, and caregiving and medical expenses (e.g. [14–16]). Maintenance expenses for IWS infrastructure add layers of financial costs, as households often need to invest in repairs and upkeep to mitigate the inconsistent water supply [17, 18].

Majuru *et al* [19] and Belmeziti [20] broadened the scope beyond IWS impacts by identifying many coping strategies associated with unreliable water sources. These included short-term behaviors such as storing water, collecting or purchasing water from backup sources, treating water, water reuse, reducing consumption, reducing hygiene practices to conserve water, and making dietary changes to accommodate limited water availability, and longer-term strategies such as installing alternative sources (e.g. drilling a well), relocating for more reliable water, and setting up illegal connections. Other reviews have expanded the known set of coping strategies broadly associated with water insecurity and intermittency to include water sharing, changing agricultural practices, and changing household routines [21, 22]. The literature thus offers a collage of hidden and sometimes invisible burdens placed on IWS consumers, revealing a complex web of coping and adaptive strategies, social disruptions, and health implications that extend beyond the immediate inconvenience of water scarcity. A deeper understanding of the downstream impacts on households and individuals could help inform and refine engineering and policy interventions aimed at addressing the challenges of IWS.

Most empirical studies investigating IWS impacts on households and individuals have focused on the connection between IWS and economic costs borne by households, e.g. [19, 23, 24], with additional emphasis on water quality [8, 11], gastrointestinal illnesses [2, 25, 26], and infrastructure repair [27]. Yet, IWS affects households and individuals through other health outcomes, such as respiratory illness [28], mosquito-borne disease [29], and mental health [30], as well as interconnected social and economic pathways, necessitating various shorter-term coping and longer-term adaptive management strategies. IWS may cause cognitive dissonance when there is a household connection to piped water that does not fulfill the expectation of free-flowing water. Binary classifications of IWS (e.g. intermittent vs continuous, predictable vs unpredictable) might obscure the wide variation in how households experience intermittency, including differences in supply frequency, duration, pressure, timing, water quality, and quantity. These differences may shape not only waterborne disease risks, but also broader health, social, economic, and coping burdens.

In response to these research gaps, we conducted a systematic review of the interdisciplinary literature on coping strategies in order to answer three research questions related to IWS in piped water supplies:

(1) What are the settings, conceptual frameworks, and forms of IWS featured in the literature?

(2) What is the breadth of human impacts that illustrates the consequences of IWS?

(3) What is the scope of coping and adaptive management strategies related to IWS, and how are they related?

We build on previous reviews by providing a comprehensive inventory of IWS-related household impacts and coping and adaptive management strategies.

2. Methods

We conducted a systematic review, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines [31], to investigate the extent of the social and health impacts of IWS as well as coping and adaptive management strategies in a broad and interdisciplinary literature base. Our process included: (1) determining and implementing the search strategy; (2) detailing eligibility criteria for relevance screening; (3) data extraction; and (4) data analysis and synthesis.

2.1. Search strategy

Search terms were designed to capture articles that analyzed the impacts of IWS on individuals or households and discussed coping strategies and adaptive management in response to IWS. Thus, keywords centered on primary terms referring to water supply, the condition of water intermittency, impacts from or responses to water intermittency, and the household or individual scale (table 1). While there is no standard definition of IWS, the term traditionally refers to intermittent *piped* water. A wide range of water supplies—from ephemeral dug wells to delivery services—are also often intermittent and unreliable, but these sources are not necessarily intended to be continuously available at the household. Because such a broad scope of intermittency could include most seasonal groundwater contexts and virtually the entire vended water literature, our review specifically focused on intermittent *piped* water supplies, consistent with the traditional definition of IWS. We used five search engines to identify articles: Web of Science, Scopus, EBSCO Academic Search Complete, PubMed, and ProQuest (details in table S1).

We conducted the searches in February and March 2024 with no date constraints and imported the results into Zotero [32] and Covidence [33]. Duplicate records were removed using Covidence's duplicate-detection function, with additional duplicates manually removed during the next stage.

2.2. Relevance screening and eligibility criteria

Articles were screened in Covidence for inclusion by the review team (authors LB, KC, SW, JS, GA, BC, PT, LS, and DF). Relevance screening was conducted in two steps. First, titles and abstracts were screened for inclusion criteria. Our inclusion criteria were that the study: (1) was about a population using piped IWS for any domestic use; and (2) discussed IWS impacts or burdens (both direct impacts and opportunity costs) at household- or individual-levels (table 2). Exclusion criteria included: (1) studies about non-piped systems (e.g. boreholes, surface water, packaged water); (2) IWS for agricultural or livestock operations; (3) studies about community-level effects only; and (4) studies describing a disaster recovery scenario (table 2). We then assessed the full text of each eligible article using the same inclusion/exclusion criteria.

At both stages, articles were independently screened by two reviewers. During title and abstract screening, the review team began by screening ∼5% of articles ($n = 600$) and then met to discuss all discrepancies in reviewers' paired assessments for inclusion and affirm consistent application of criteria. The team then reviewed another 5% of articles and met again, iteratively repeating the process of discussing conflicts and clarifying inclusion and exclusion criteria. The team repeated this process during full-text screening, recalibrating after reviewing ∼10% of articles ($n = 35$). Final resolution was centralized and handled by the lead and corresponding authors. During the full-text screening process, Covidence produced kappa statistics to assess inter-rater reliability.

2.3. Data extraction

After full-text screening of candidate articles, we extracted key article data elements, again performed independently by two team members (blinded to others' results), and recalibrated using the same process as before. The extracted data comprised three general categories:

1. General study characteristics, such as its location; whether the study was conducted in an urban, peri-urban, or rural context; the conceptual framework employed (see definition below); and the research design (methodological approach, sample size, study scale, and dates of data collection);
2. IWS characteristics, including whether the IWS context was discussed explicitly or implied; the type of IWS system; IWS indicators (e.g. hours of supply, pressure levels, supply reliability);
3. Household and individual impacts or burdens; coping and adaptation strategies employed (using a codebook described in section 2.4); and any other quantitative measures included in the analysis.

2.3.1. Conceptual framework classification

Studies' conceptual framework(s) were extracted to text with no *a priori* classification given their multidisciplinary nature; we recorded frameworks for 87 of the 140 included studies. We used Google's large language model (LLM) Gemini 2.5 Flash, to suggest an initial classification system of 5–10 categories (allowing for an 'other' category) for the extracted framework descriptions (see the appendix in the Supplementary Material for the AI prompt and output). The LLM was only used to generate preliminary categories and assignments of each study to a category. The research team reviewed and refined the suggested classification scheme, resulting in six conceptual frameworks (table S2): (1) *Economic*

Table 1. Abbreviated version of the search strategy used to identify published articles which analyze impacts, coping strategies, or adaptive management related to IWS.

Main terms	Expanded terms
Water supply	'Drinking water' OR 'piped water' OR 'water suppl*' OR 'potable water' OR 'municipal water' OR 'tap water'
Condition	'insecur*' OR 'secur*' OR 'scarc*' OR 'shortage*' OR 'shutoff*' OR 'intermittent*' OR 'interrupt*' OR 'ration*' OR 'reliab*' OR 'unreliab*' OR 'unpredictab*' OR 'predictab*' OR 'outage*' OR 'access' OR 'unavailab*' OR 'availab*'
Impacts or Response	'Adapt' OR 'coping' OR 'cope' OR 'cost*' OR 'response*' OR 'consumption' OR 'manag*' OR 'strategy' OR 'filt*' OR 'health'
Scale	'Household' OR 'home' OR 'domestic' OR 'residen*'

Table 2. Inclusion and exclusion criteria applied during all stages of the review.

Inclusion	Exclusion
• Piped IWS for any domestic use (include if 'piped' water supply is unclear in abstract). • Discusses IWS impacts or burdens (both direct and opportunity costs) at the household- or individual-level. • Any urban, peri-urban, or rural context. • Studies of coping strategies (short-term responses) at household or individual levels to IWS shocks. • Adaptive management at the household or individual levels (long-term responses) to IWS impacts. • Health studies not related to water quality or gastrointestinal infections (GII), such as social, emotional, mental health, or interpersonal violence impacts of IWS. • Packaged water use as a direct response to IWS, rather than related to general water insecurity. • Willingness-to-pay studies that are framed as a response to IWS.	• Non-piped systems such as boreholes, surface water, packaged water, etc. • IWS only in the context of agricultural or livestock operations. • Community-level effects. • Disaster recovery scenarios. • Studies about infrastructure operations and maintenance at the system or governance level, hydrological modeling studies of household water consumption, or water safety plans that do not analyze household or individual impacts/coping/adaptation. • General water insecurity studies (e.g. associated with exclusion, politics, etc) that are not directly related to IWS.

Valuation—assigned monetary value to water services using stated or revealed preferences, such as willingness-to-pay or contingent valuation studies; (2) *Behavioral and Consumer Response Models*—assessed how individuals or households perceive, react to, or cope with IWS, focusing on decision-making and non-monetary costs; (3) *Political Ecology, Governance, and Social Justice*—analyzed water access within broader political, social, and power structures; (4) *Public Health and Environmental Epidemiology*—focused on health outcomes and disease vectors associated with intermittent water quality and quantity; (5) *Social and Development Theory*—used theoretical approaches related to development, social stratification, livelihoods, and human dimensions of water access; and (6) *Hydrological and Engineering Modeling*—focused on the physical or technological aspects of water systems, such as water consumption studies.

The AI output included an additional Knowledge, Attitudes, and Practices category, which we consolidated into Behavioral and Consumer Response Models. Studies initially labeled 'Research Design and Methods,' 'Miscellaneous' or those without a clear recorded conceptual framework were re-examined by the research team using their titles and abstracts and re-classified within the six categories. Ambiguous classifications were resolved through team discussion and consensus.

2.3.2. IWS characteristics

IWS systems described in the included studies were evaluated according to whether the system was explicitly defined or described as IWS or whether IWS was implicitly described, i.e. inferred from context. Systems were categorized according to one or more of the following descriptions: (1) *Continuous supply but with intermittent pressure*—any reference to inadequate pressure (i.e. pressure was either intermittent or the pressure levels would vary); (2) *Intermittent supply with predictable hours*—reference to features such as hours, timing, days, or duration of supply being predictable; (3) *Intermittent supply with unpredictable hours*—reference to hours, timing, days, or duration of supply was unpredictable; (4) *Intermittent supply with predictable quantity*—reference to volume of supply was predictable; (5) *Intermittent supply with unpredictable quantity*—reference to volume of supply was unpredictable; (6) *Intermittent supply with unreliable water quality*—water quality was either variable or generally poor in nature; (7) *Related to an electricity or energy disruption*—at the water utility or home; or (8) *Unspecified*—the system was described as IWS but with no other information.

Table 3. Coding hierarchy, descriptions, and examples from the codebook for household- and individual-level coping and adaptive management strategies originating in Thomson *et al* [34].

Code category	Code	Description	Examples
Intensification	1.1 Own labor	Own-labor water acquisition	Walking to collect water, digging a new borehole
	1.2 Production	Low-yield water acquisition	Using existing water storage infrastructure, using existing rainwater collection systems
	1.3 Trade	Earning income to buy water	Purchasing bottled water, buying water from a vendor
	1.4 Transfer	Borrowing, taking credit or loans, or selling assets to get water	Borrowing water from neighbors
Modified consumption	2.1 Rationing (self)	Cutting back water use	Reducing bathing, hygiene
	2.2 Modification or substitution	Making substitutions or modifications	Treating drinking water before consumption (e.g. water filter)
	2.3 Stigma	Consuming proscribed or stigmatized water	Collecting domestic water from a source known as contaminated
Migration	3.1 Foster	Fostering out children	Children being sent away to live with no adults accompanying
	3.2 Migrate	Seasonal or temporary migration	Family member temporarily moving away to work
	3.3 Resettle	Resettling the household permanently	Moved to another house
Reprioritization and withdrawal	4.1 Withdraw (extra-household)	Withdrawing from resource-sharing obligations	Refusing to pay water utility bill
	4.2 Reprioritize (within household)	Prioritizing certain household members' needs	Prioritizing men's water needs
Psychosocial and spiritual responses	5.1 Psychosocial coping	Psychological coping	Feeling stress, complaining
	5.2 Spiritual coping	Spiritual coping	Local religious creeds about conserving water
Adaptive management	Adaptive management	Planning and knowledge sharing to enhance capacity to respond to change	Participatory water policy; collective action in a neighborhood water committee

We also recorded the type of IWS indicator(s) used: (1) hours of supply per day or week; (2) days of supply per week or month; (3) pressure levels; (4) general reliability/predictability of supply (i.e. water supply was 'unpredictable' but quantitative measures such as hours or days not specified); (5) water quality parameters; or (6) no indicators were specified. Studies could include multiple indicators.

2.3.3. Coping and adaptive management coding

Each study was then coded for coping and adaptive management strategies pursued by individuals or households in response to IWS. Our team developed and applied a codebook for individual and household coping strategies in the context of IWS in collaboration with the Arizona Water for All (AW4A) initiative [34]. This codebook was informed by Sen's [35] entitlement framework and existing literature on coping strategies, specifically citing work by Achore *et al* [22]; Collins *et al* [36]; Majuru *et al* [19]; Pahl-Wostl [37]; Scot *et al* [38]; Tompkins and Adger [39]; Venkataramanan *et al* [21]; and Wutich and Brewis [40]. Sen's [35] entitlement framework provides the foundation for the Intensification coping strategies, including: 1.1 Own labor, 1.2 Production, 1.3 Trade, and 1.4 Transfer (table 3). More details regarding the theoretical construction of the codebook are in Thomson *et al* [34].

Table 3 provides detailed descriptions and examples of the codebook's 15 codes across five coping domains (Intensification, Modified Consumption, Migration, Reprioritization and Withdrawal, Psychosocial and Spiritual Responses) and one adaptive management domain (Adaptive Management).

2.3.4. Codebook validation and inter-rater reliability

To ensure its validity and robustness, the codebook was tested and refined by 8 lead coders through iterative coding and comparison exercises. A minimum Cohen's kappa [41] of 0.60 was established for each of the 15 codes as the threshold for acceptance agreement, following Landis and Koch [42]. The mean Cohen's kappa across all 15 codes was 0.825; a Cohen's Kappa $\geqslant$ 0.8 implied 'almost perfect' agreement [42]. Before starting data extraction, each team member underwent an Inter-Rater Reliability

exercise, iterated until all coders achieved a Cohen's kappa $\geqslant 0.60$ against the coding of one of the primary coders.

2.4. Data analysis and synthesis

First, the overall study characteristics were summarized: region/continent, setting (e.g. rural, urban), study design, research approach/data collection methods, study scale, explicitness of IWS use in the paper, IWS type, IWS indicators, household impacts, coping strategies, and adaptive management. Second, we mapped the site locations of each included study to summarize the geographical context and test regional patterns for IWS type, household impacts, and coping strategies and adaptive management using chi-square statistics in Matlab (version R2023b). We used the World Resources Institute's 2023 country-level water stress scores as a base layer, where darker tones indicate higher water stress scores and more competition among users [43].

Next, we summarized the human impacts categorized during data extraction and the coping and adaptive management strategies derived from our codebook, analyzed across the six conceptual frameworks to understand contributions by subdiscipline. We computed a circle graph using Matlab to visualize the most frequent co-occurrence of coping and adaptive management codes. The strategies were transposed into pairs, such as *Own Labor–Rationing* and *Trade–Psychosocial* (ignoring the order of strategies within the pairs, i.e. *Transfer–Trade* is the same as *Trade–Transfer*). A study describing two coping codes yielded one pair (A–B), three codes yielded three pairs (A–B, A–C, B–C), and so on. Heat maps were also created to visualize the co-occurrence and the human impacts with different types of IWS. We analyzed co-occurrence of each pair of IWS type and an impact or coping code and computed Fischer's exact test, with a correction for multiple tests, to identify significant relationships. We used tiled heat maps to visualize these pairwise relationships. Analyses and visualizations were performed using R (version 4.6.0), Python (version 3.11.11) and IBM SPSS Statistics (version 29).

3. Results

Figure 1 presents the PRISMA diagram summarizing our review process. Our keyword search strategy yielded 22 766 records across five scholarly databases, with 10 330 duplicates automatically removed by Covidence, and another 12 085 excluded after title and abstract screening. Our full-text review of the remaining 351 candidate studies yielded a final set of 140 studies for analysis. During full-text review, pairwise reviewer agreement was 86.0% with kappa (inter-rater reliability) > 0.6 for 87.8% of reviewed studies, with discordant review pairs discussed by the team. The data file containing the full characteristics of the 140 included studies is freely available here: https://doi.org/10.17604/2sfe-3v64.

There were 211 studies that appeared to meet inclusion criteria based on the title and abstract but were excluded after the full-text review. Many of these excluded studies discussed household and individual impacts or coping strategies related to poor water access but often did not explicitly frame the impacts or coping strategies in the context of piped IWS (e.g. [44–48]), presented an overview without primary data collection (e.g. [12, 22, 49, 50]), or dealt with IWS from a utility perspective and did not explicitly measure household- or individual-level impacts or coping strategies (e.g. [51–54]).

3.1. Study characteristics

Table S3 presents the characteristics of reviewed papers: study design, research approach/data collection methods, region/continent, setting (e.g. rural, urban), study scale, explicitness of IWS in the paper, IWS type, IWS indicators, household impacts, as well as coping and adaptive management strategies. Most studies used quantitative approaches (120, 85.7%), over half (78, 55.7%) employed qualitative approaches, and 59 studies (42.1%) used mixed methods or multiple approaches. Among the quantitative studies, household surveys were most commonly used (117, 83.6%). Qualitative data collection methods also included interviews (61, 43.6%), direct observation (23, 16.4%), focus groups (19, 13.6%), and ethnography (10, 7.1%). Most studies examined household-level responses (121, 86.4%), with sample sizes ranging from 12 to 4 082 households or individuals.

3.1.1. Study locations

Studies were conducted across 36 different low-, middle-, and high-income countries (figure 2), with India (23, 16.4%) and Ghana (15, 10.7%) as the two most studied (table S3). Likewise, Sub-Saharan Africa (48, 34.3%) and South Asia (41, 29.3%) were the most common regions, followed by North America (17, 12.1%), Central and East Asia (11, 7.9%), Middle East and North Africa (10, 7.1%), South America (8, 5.7%), Europe (4, 2.9%), and Oceania (1, 0.7%). Most studies were conducted in urban settings (100, 67.1%), with an additional 27 studies (19.3%) examining mixed settings, while fewer studies focused exclusively on rural (20, 14.3%) or peri-urban (11, 7.9%) contexts.

Studies were located in countries with varying degrees of water stress (figure 2). The highest number of studies were in Accra, Ghana (11, water stress score [WSS] = 0.11, 'low water stress'), Kathmandu, Nepal (10, WSS = 3.18, 'high water stress'), and Amman, Jordan (6, WSS = 4.62, 'extremely high water stress'). The three most water-stressed countries represented were Cyprus (1, WSS = 5), Botswana (4, WSS = 4.66),

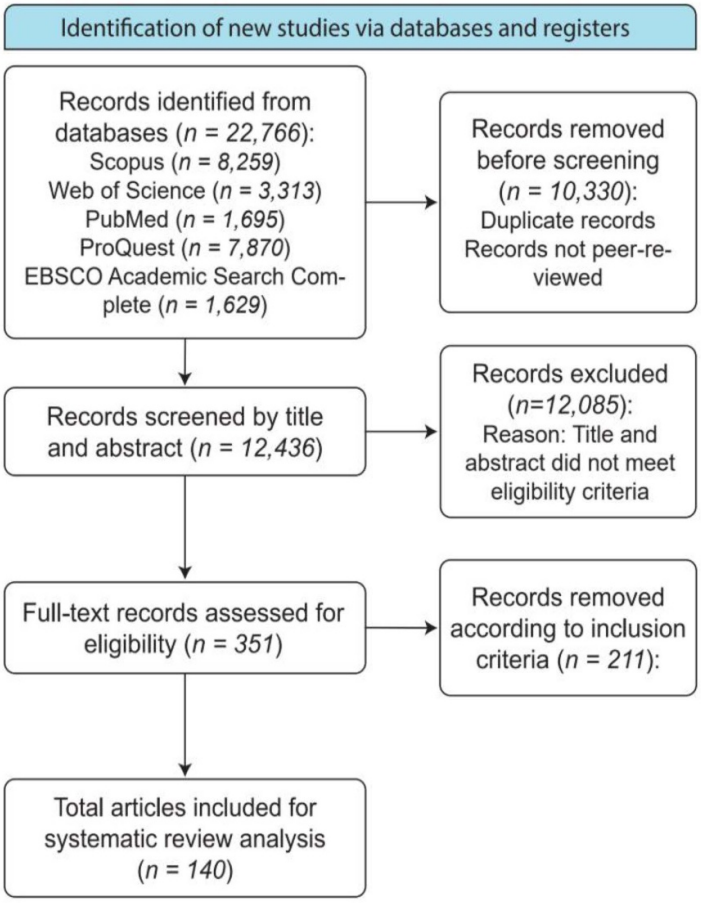


Figure 1. PRISMA flow diagram showing our steps in reducing 22 766 records from keyword searches of five scholarly databases into a final set of 140 studies for analysis.

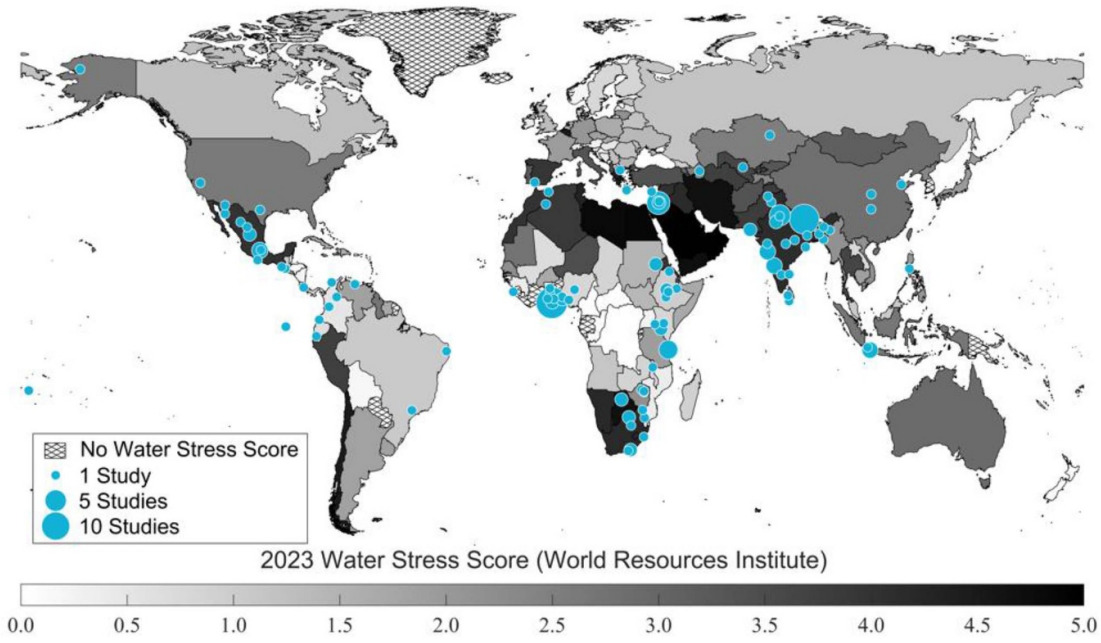


Figure 2. Study locations of 140 identified studies describing IWS coping strategies published between 1994–2023. Study locations are layered over the World Resources Institute's 2023 country-level water stress score (in gray tones), which range from 0.0 (low water stress) to 5.0 (extremely high water stress) and are calculated as a ratio of total water demand to available renewable water supplies for domestic, industrial, irrigation and livestock consumptive and non-consumptive uses (Water Resource Institute, 2023). Countries depicted with the hatched pattern lacked sufficient data to compute a score.

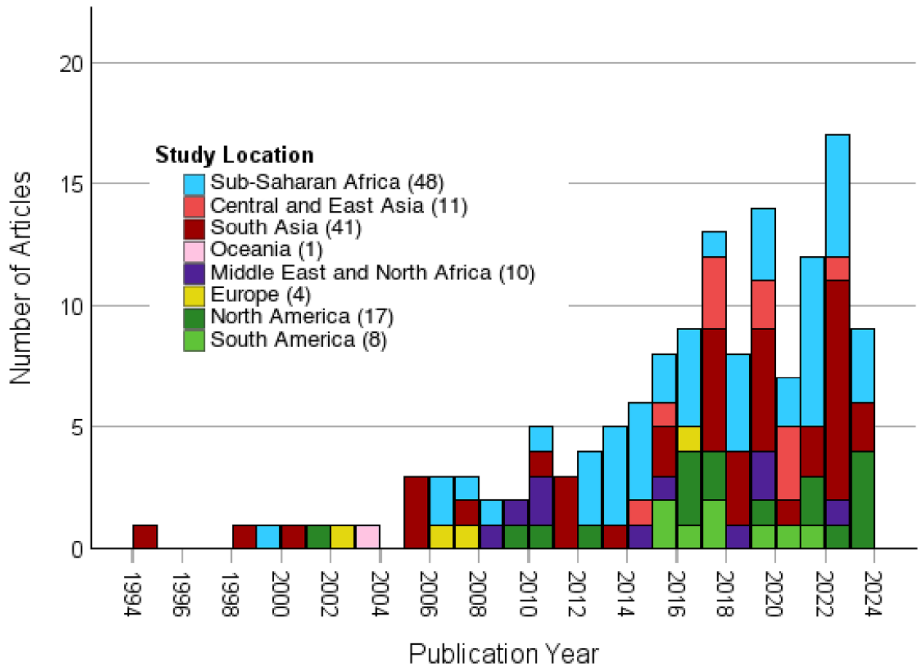


Figure 3. Number of IWS studies, by world region, that address coping strategies or adaptive management.

and Jordan (8, WSS = 4.62). Conversely, the three least water-stressed countries represented were Ghana (15, WSS = 0.11), Colombia (1, WSS = 0.5), and Costa Rica (1, WSS = 0.65).

To assess potential geographical drivers, study locations were categorized into eight regions and tested for regional patterns by IWS type ($\chi^2 = 54.5$, $P = 0.274$), household impacts ($\chi^2 = 142.4$, $P = 0.151$), and coping strategies and adaptive management ($\chi^2 = 58.3$, $P = 0.985$), but none of these relationships were significant.

3.1.2. Publication trends over time

The annual number of published studies ranged from 0–1 from 1994 to 2004, then increased steadily from 5–17 between 2005–2023 (figure 3). The earliest IWS studies to address coping strategies in our review were conducted in South Asia and Sub-Saharan Africa, which remained the most common sites, respectively accounting for 41 and 48 of the included studies, followed by North America (17), Central and East Asia (11), Middle East and North Africa (10), South America ($n = 8$), Europe (4), and Oceania (1). There was a more pronounced increase in study frequency beginning in 2014, with 103 (73.6%) published during 2014–2023.

3.1.3. Conceptual frameworks

Over a third (47, 33.6%) of the 140 included studies used *Behavioral and Consumer Response Models*, i.e. how individuals or households perceive, react to, or cope with IWS (e.g. decision-making and non-monetary costs) (table S2). The next most common frameworks were *Economic Valuation* (24, 17.1%), assigning monetary value to water services or assessing the costs and welfare changes associated with IWS, and *Public Health and Environmental Epidemiology* studies (23, 16.4%), the health outcomes (e.g. gastrointestinal illnesses, skin lesions, and vector-borne diseases) associated with IWS. Studies employing *Political Ecology, Governance, and Social Justice* frameworks (20, 14.3%) generally focused on power structures and policy effects, whereas studies oriented around *Social and Development Theory* (16, 11.4%) reflected themes such as social stratification, livelihoods, and the human dimensions of water access. Finally, ten studies (7.1%) categorized as *Hydrological and Engineering Modeling* focused on physical or technological aspects of IWS through water consumption studies or assessments of decentralized systems such as rainwater harvesting. The six conceptual frameworks reflect interdisciplinary interest in the global impacts and coping strategies of IWS.

3.2. IWS characteristics

IWS was explicitly stated or defined in 80% of the studies (112) (table S3). Nearly two-thirds (88, 62.9%) described different forms of intermittency, such as predictable hours of supply, unreliable water quality (meaning generally low or variable water quality), and continuous supply but with intermittent pressure (meaning pressure was either intermittent or variable). More than one type of intermittency was referenced in 41.4% of studies (58), and eight included four or more types, underscoring the wide variety of ways that households experience intermittency.

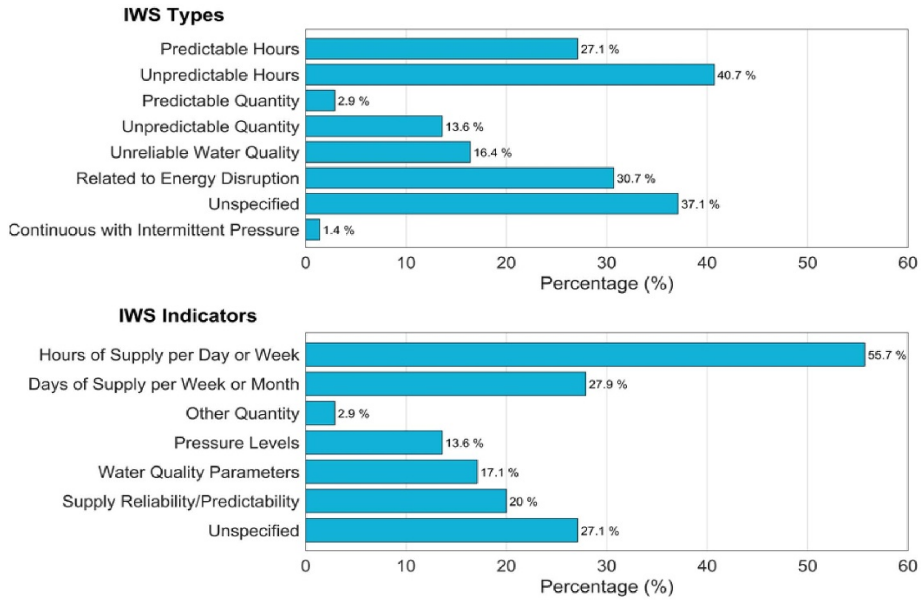


Figure 4. Percentage of identified studies that describe IWS by type and indicators of supply.

IWS with unpredictable hours was the most frequent (57, 40.7%), followed by 'Unspecified' (52, 37.1%) (figure 4). Forty-three studies (30.7%) stated that IWS was related to energy disruption at the water utility/supplier level or consumer side, drawing a connection between other infrastructure services and coping strategies. As an example, a Principal Water Engineer in Ngamiland (Botswana) shared that unreliability of water supply was due to the breakdown of diesel-fueled pumps and the failure to deliver diesel fuel at the water utility [55]. On the island of Crete, where electricity shortages were not uncommon, households experienced a 'paradoxical situation of having a full tank but being unable to pump the water so that it is distributed to all faucets' [56].

Most studies (102, 72.9%) described intermittency using an indicator such as hours of supply, reliability, and/or pressure levels, with over a third referencing more than one indicator (54, 38.6%). The most frequent indicator was hours of supply per day or week (78, 55.7%), followed by days of supply per week or month (39, 27.9%), while many remained *unspecified* (38, 27.1%), showing that many IWS studies do not define system characteristics (figure 4).

3.3. Impacts

Economic impacts were most frequently reported, including increased spending, time lost managing water, and livelihood disruptions (figure 5). Most included studies (115, 82.1%), discussed high household spending in response to IWS, which reflected in high water prices (i.e. vendors increasing prices of water due to demand), needing to purchase chemicals to treat water, the cost of treating waterborne diseases, buying storage containers, or purchasing water from other sources, such as water kiosks, water trucks, sachet water, or bottled water. Over half of studies reported time lost managing water (83, 59.3%), which included spending more time pursuing alternative water sources and queuing in line to collect water. Just under half, (69, 49.3%), discussed livelihood disruptions, which referred to general disruptions due to altering of schedules around water availability, entrepreneurial opportunities being constrained due to lack of water, inability to cook or prepare food for sale, childcare disruptions, and inability to water commercial gardens. Just 16 studies (11%) specifically described missing or being late to school because of IWS. Only three studies (2.1%) described housing costs due to IWS, which included displacement from affordable housing, changes in property values, and increased rent.

The most frequent health-relevant impact was poor water quality, where two thirds of studies (94, 67.1%), discussed poor organoleptic properties including smell, taste, and appearance of water as well as increased measured contamination (figure 5). Nearly half of the studies (63, 45%) identified hygiene/sanitation disruptions in response to IWS, including foregoing showering, using less water for bathing, and insufficient water for flushing toilets. About a third discussed infectious diseases generally (52, 37.1%), including waterborne diseases (both explicitly specified and implicitly with context such as 'getting sick from the water'), bacterial infections, and skin lesions. Several studies (27, 19.3%) discussed, and sometimes measured, the mental health impacts of IWS, which included individuals experiencing stress about intermittency of water. Less frequent impacts included vector-borne diseases (16, 11.4%), i.e. mosquito-borne diseases (primarily dengue or zika, but also malaria) associated with breeding in

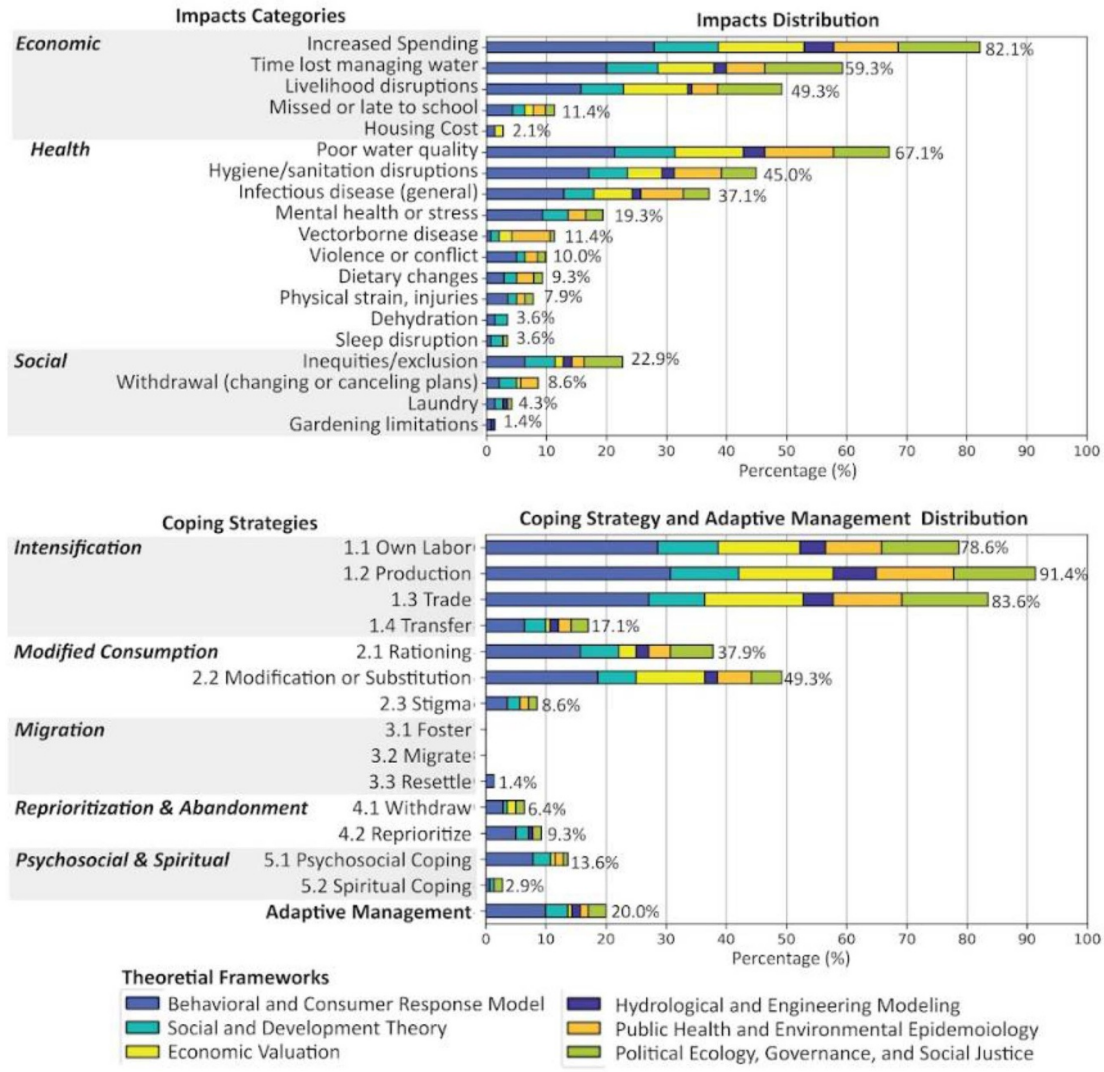


Figure 5. Impacts and coping and adaptive management strategies identified across studies according to the theoretical framework the study employed for analysis. Theoretical frameworks include (1) Behavioral and Consumer Response Model; (2) Social and Development Theory; (3) Economic Valuation; (4) Hydrological and Engineering Modeling; (5) Public Health and Environmental Epidemiology; and (6) Political Ecology, Governance, and Social Justice.

unprotected water storage containers or other standing water that were part of an IWS coping strategy. Ten percent of articles ($n = 14$) discussed violence or conflict, i.e. fighting or verbal altercations at water sources or when queuing for water and inter-household conflict from insufficient water due to intermittency or rationing. Thirteen studies reported dietary changes (9.3%), including cooking alternative foods, due to water limitations, and 11 studies (7.9%) reported physical strain and injuries from having to collect and carry water from alternative water sources. Five studies (3.6%) reported dehydration due to low water consumption, and another five reported sleep disruptions due to having to wake in the middle of the night to collect water.

Social impacts due to IWS include social inequities/exclusion (32, 22.9%), such as poorer parts of a town or city having IWS while the more affluent areas had continuous services or when continuous supply was prioritized to certain ethnic groups (figure 5). Withdrawal or having to change or cancel plans due to IWS was described in 12 articles (8.6%). Laundry limitations, i.e. not enough water to do laundry or water that was 'dirty' due to IWS and affected the color of clothes, was found in six studies (4.3%). Finally, two studies (1.4%) reported not having enough water for gardens.

3.4. Coping and adaptive management strategies

The most frequent coping codes were *Production, Trade*, and *Own Labor* (figure 5). Nearly all studies (128, 91.4%) referred to *Production*, such as using existing storage vessels, rainwater collection systems, or pumping systems to secure more water. The next most frequent code was *Trade* (117, 83.6%), which includes purchasing water. The third most frequent coping code was *Own Labor* (110, 78.6%), describing strategies such as walking to another water source to

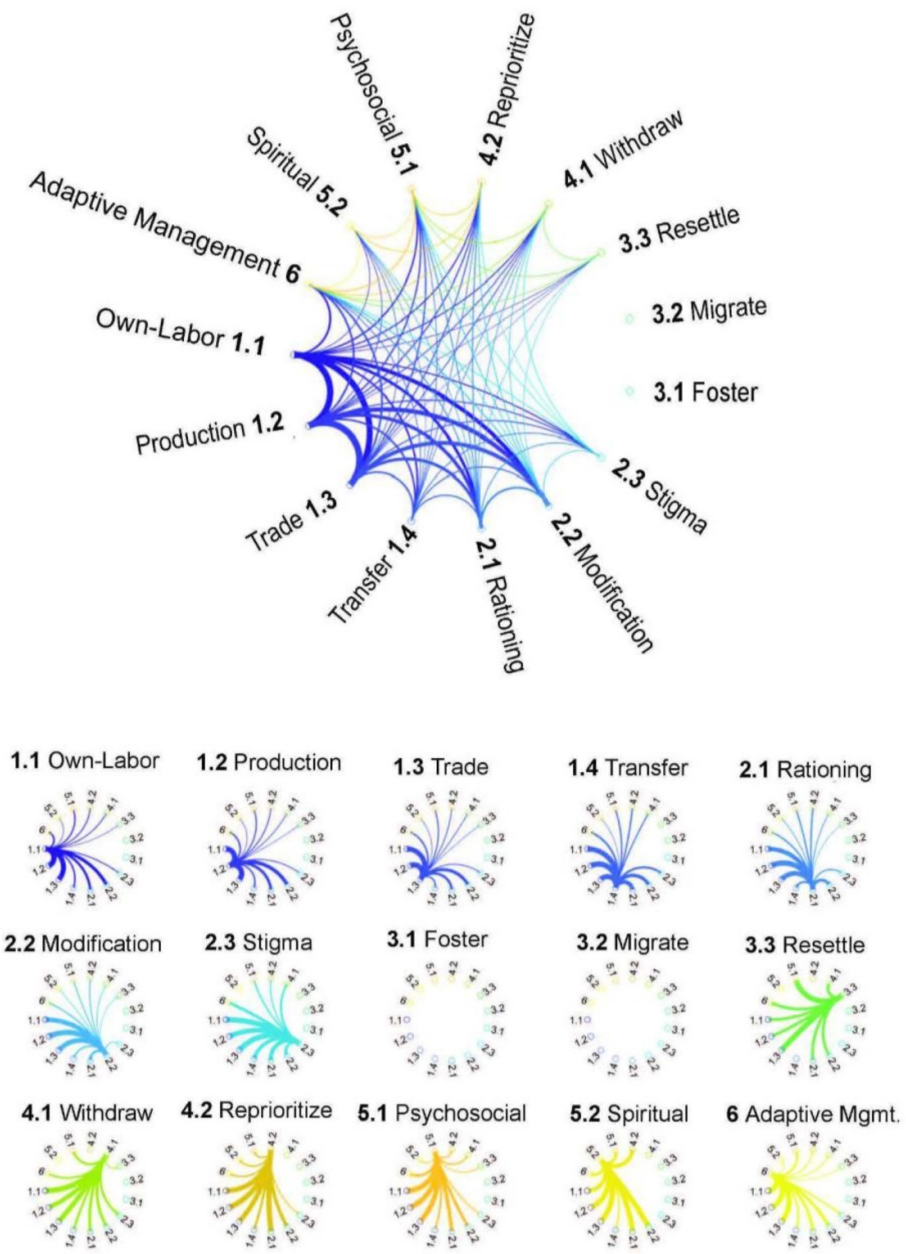


Figure 6. Circle graphs visualizing co-occurrence among the 15 coping and adaptive management codes. Line thickness within each circle is scaled to how frequently the respective pair was coded from the same study.

collect water. A fifth of studies (28, 20%) indicated adaptive management strategies to cope with IWS, which included actions such as households within a community organizing to protest intermittency of water services.

Households often pursued multiple strategies simultaneously, such that coping and adaptive management codes often co-occurred (figure 6). The most frequently co-occurring pairs were *Production* and *Trade* (110), *Production* and *Own Labor* (107), and *Own Labor* and *Trade* (101), which reflected the top three coping codes (see table S3).

Finally, we explored the relationship between IWS type and impacts as well as coping codes and adaptive management (figure 7). IWS with unpredictable hours was significantly related to the impacts of time lost managing water (44, 31.4%) and livelihood disruptions (39, 27.9%). We also found the unspecified IWS type related to increased spending (35, 25.0%) (figure 7(A)). We did not find any significant relationships between IWS type and coping codes (figure 7(B)).

4. Discussion

We systematically reviewed and synthesized 140 studies describing the many contexts of IWS, its human impacts, and the diverse coping and adaptive management strategies deployed around the world to buffer

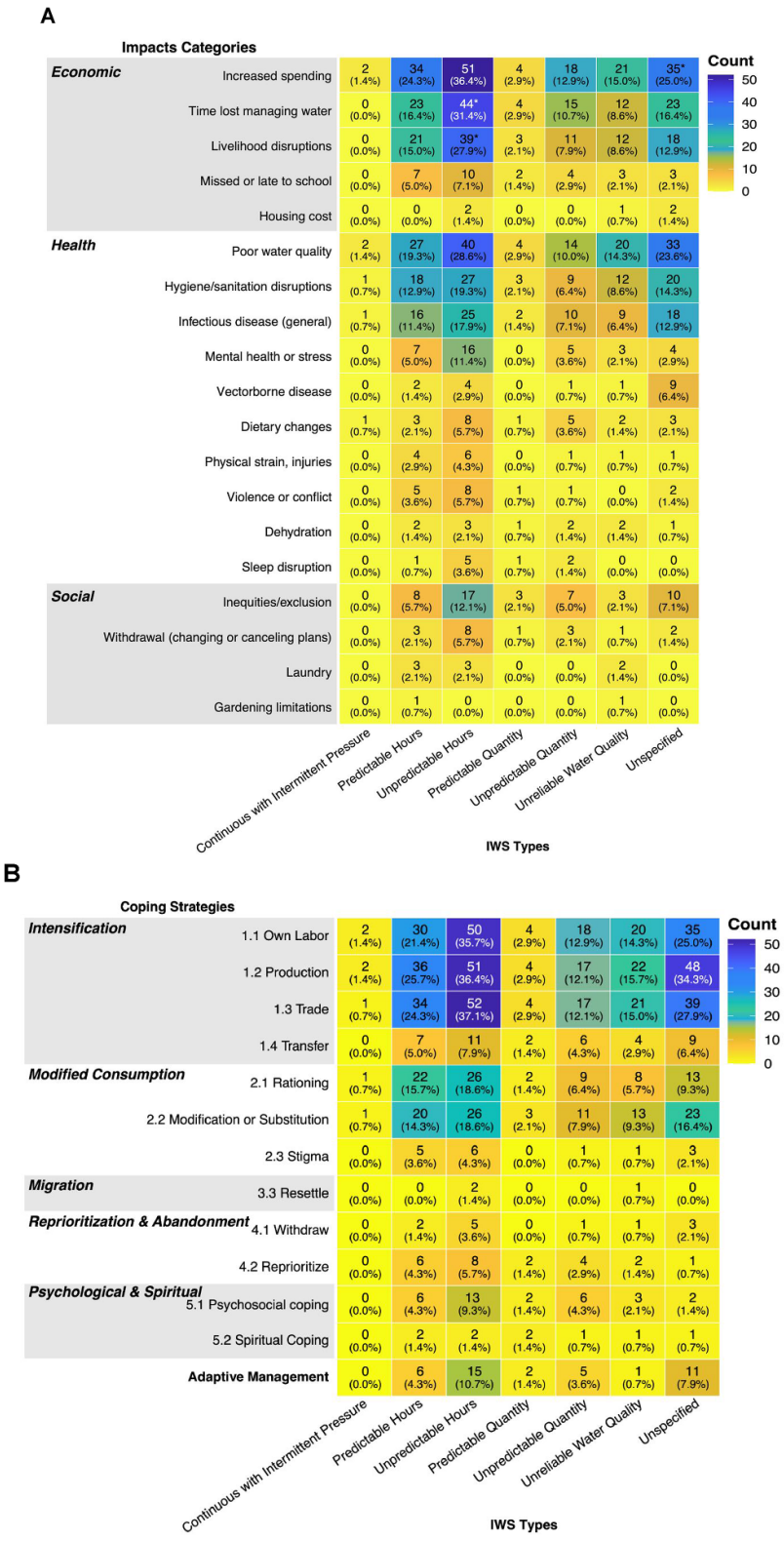


Figure 7. Frequencies of (A) impacts, and (B) coping codes and adaptive management, by IWS Type. Significance evaluated with Fisher's exact test with a Benjamini–Hochberg correction for multiple comparisons. Counts annotated with an asterisk are significant with $P < 0.05$.

households and individuals from IWS. Through this work, we applied a novel codebook to categorize, analyze, and identify gaps in the literature related to coping and adaptive management strategies specifically in response to IWS. This review builds upon other work that has demonstrated coping in response to IWS [1, 9, 16, 19–21] with additional impacts and coping in studies representing almost every continent, at all levels of national wealth, and irrespective of variations in local water stress. IWS is indeed

a global phenomenon with the scientific literature increasingly acknowledging its human impacts and coping costs. Given ongoing pressure on water systems from population growth, infrastructure degradation, and extreme weather, IWS may become a mainstay in piped water provision and therefore presents many opportunities for improving human health, livelihoods, and social well-being. We unpack the key findings and implications of our review in the sections below.

4.1. Study characteristics

The diversity of study designs, sample sizes, geographical locations, and degree of local water stress in individual study settings suggests that a rich, growing, multidisciplinary literature has emerged on IWS-related household impacts and coping strategies. The geographical distribution of studies was skewed toward countries with the least-developed water infrastructure, though focused in South Asia and Sub-Saharan Africa and developing cities that were politically stable and conducive to water research over the past thirty years (e.g. Accra, Kathmandu, Amman). Many of the IWS studies we analyzed were not situated in water stressed locations, a reminder that IWS is not necessarily an indicator of water scarcity but is related to other social and governance issues.

The diversity of research approaches was also dominated by two categories of conceptual frameworks—*Behavioral and Consumer Response Models* and *Economic Valuation*—which accounted for half of the included studies. There seem to be more opportunities for IWS research contributions from the public health, governance, and social development domains for identifying mechanisms that mitigate IWS impacts and their concomitant coping strategies. Few studies used a *Hydrological and Engineering Modeling* framework, perhaps because these disciplines are more likely to approach IWS at the system-level rather than an individual or household level. This finding may also reflect a disconnect between many IWS operators and their users.

4.2. IWS characteristics

IWS is often oversimplified as a singular service condition in the literature, namely reduced hours of supply. Yet our work reveals that IWS manifests across a spectrum of overlapping service characteristics, including limited duration, unpredictable timing, intermittent or variable pressure, and fluctuating or generally poor water quality. More than one type of intermittency was frequently referenced, suggesting that households often experience IWS through multiple overlapping service failures rather than a singular type. A household may receive water on a predictable schedule while still experiencing low pressure, poor quality, or inadequate quantity; another may have a piped connection but face unpredictable delivery, night-time supply, or insufficient pressure to fill storage containers. This distinction matters because different forms of IWS impose different household burdens, and the way intermittency is defined shapes how its impacts are interpreted. In any case, IWS shifts responsibility for reliability from the supplier to the household or building. Households then respond with coping strategies, which may reduce immediate risk but also introduce new costs and vulnerabilities. Storage can protect against short interruptions but may increase contamination risks; purchased water may reduce perceived health risk but increase affordability burdens; and pumping can improve pressure or in-house access for some households while reducing pressure for others. Thus, coping with IWS can both reduce and reproduce water insecurity.

The indicators used to describe IWS further demonstrate the limits of duration-based measurement. Hours of supply per day or week was the most common, followed by days of supply per week or month. These measures are valuable for comparison across settings, but they do not capture the full lived experience of intermittency. Duration-based indicators do not necessarily indicate whether supply arrives at usable times, whether pressure is sufficient, whether delivery is predictable, or whether households can safely store and use water once it arrives. IWS should therefore be understood as a multidimensional condition composed of duration, frequency, predictability, pressure, timing, seasonality, water quality, quantity received, and coping requirements.

The finding that one-third of studies linked IWS to energy disruption further expands how IWS should be understood within the water-energy nexus, and was also noted by Simukonda *et al* [9]. Electricity and fuel are often underappreciated influences in water supply research, yet many systems depend on energy for abstraction, pumping, treatment, storage, pressurization, and distribution. For utilities or water suppliers, power outages, diesel shortages, electricity debts, fuel delivery failures, pump breakdowns, and motor failures can reduce supply duration, pressure, and reliability. These disruptions may appear in household accounts as unpredictable hours, low pressure, compromised water quality, dry taps, or reliance on alternative sources.

Energy also shapes household coping: when supply is intermittent, households may depend on electric pumps, boreholes, suction pumps, home water treatment units, storage systems, boiling, or commercial water to ensure continuous water availability within the household. These water practices are also energy-dependent practices. If electricity is unavailable, for example due to grid instability or rolling outages, stored water may not reach taps, borehole water may not be extracted, and filtration systems may not function. If energy is expensive, households may reduce pump use, change storage practices, or switch

to commercial water to avoid boiling or other energy-intensive treatment. Electricity therefore affects both the production of intermittent supply and the household capacity to cope with it—even when water is available. This is particularly problematic because water insecurity and energy insecurity can co-occur; households experiencing water intermittencies may also be more likely to have limited energy availability.

Water utilities, community systems, vendors, and households all operate within energy-dependent service chains. Avordeh *et al* [57] show that unreliable electricity disrupts micro, small, and medium-sized enterprises by reducing productivity, increasing operating costs, interrupting supply chains, and limiting income generation. Although their review focuses on enterprises rather than water systems, the same logic applies to household water insecurity. When electricity fails, the consequences cascade into water access, affordability, hygiene, time use, and livelihood disruptions. Electricity should therefore be understood not as a background utility, but as a cross-infrastructure determinant of water security.

4.3. Impacts of IWS

Our review identified a broader set of IWS-related health impacts than previously documented. Notably, while waterborne gastrointestinal illnesses can directly result from compromised water quality in intermittent pipes [13], many other health outcomes can indirectly result from the coping strategies households adopt in response to IWS. For example, limiting or rationing water use can hamper hygiene and increase the risk of bacterial infections or respiratory infections [58, 59], and storing water between supply cycles can amplify vector-borne diseases by providing mosquito breeding habitat [29, 60]. Systems can experience transient or chronic intermittencies, which include a wide range of supply frequencies and durations [1, 11, 20]. More recent evidence suggests that different intermittency patterns drive different health risks. A recent study of transient intermittencies in Malawi found that infrequent interruptions to water supplies were associated with diarrhea, while frequent or long interruptions were associated with respiratory infections, and frequent or short interruptions were associated with stress [28]. In India, waterborne disease risks among IWS households with higher frequency and longer duration of supply were comparable to continuous water supply but significantly elevated among IWS households with lower frequency and shorter duration of supply [61]. Efforts to mitigate health impacts from IWS in a given setting should incorporate endpoints beyond diarrheal disease and consider the effects of different intermittency patterns. IWS systems should identify modes of operation in terms of supply frequency and duration that minimize health impacts and coping strategies adopted.

Our review focused on the direct effects of IWS, but IWS may also have negative *indirect* effects on individuals and households through other pathways. For example, when intermittency prevents people from cooking at home, it may drive people to purchase prepared and often less healthy food alternatives. In a household survey investigating spatial variation in IWS and the associated consumer responses in Kenya, one respondent reported that water supply problems led to 'budget issues since [they] went for fast foods that are way expensive' [62]. Almost 10% of the studies in our review (9.3%) indicated some kind of dietary impact related to IWS, consistent with literature demonstrating adverse food and nutrition related coping strategies in response to water insecurity [63]. Future research should investigate how improvements to IWS, whether related to absolute supply, its predictability, or how intermittency is communicated, may improve household food security, nutrition, and other health indicators.

4.4. Coping and adaptive management strategies

One of this study's innovations was the application of a novel codebook that defines five coping domains and is grounded in the coping literature. As a result, our review identified a more comprehensive set of IWS-related coping strategies and adaptive management practices than previous reviews [9, 19, 20]. For example, we synthesized evidence of borrowing water from neighbors or kin (i.e. *Transfer*), collecting water from a source known as contaminated (*Stigma*), and refusing to pay a water utility bill (*Withdrawal*) in response to IWS. We also identified intra-household dynamics such as prioritizing needs for certain members of the household (*Reprioritize*) and cognitive coping approaches such as feeling stress and complaining (*Psychosocial*) and following local religious creeds about conserving water (*Spiritual Coping*). All of these coping strategies mirror those found in the broader water insecurity literature [21, 22]. We also advanced the evidence base related to adaptive management (e.g. collective community action in a neighborhood water committee) which was found in a fifth of the reviewed studies. In contrast, Belmeziti [20] described only one study (out of 81) that signaled a community-level response to IWS.

There were notable gaps in the literature documenting migration as a coping strategy. Few papers documented migration and none related to the codes *Fostering* and *Migrating*. One reason for this might be that we excluded studies describing a disaster recovery scenario, where water insecurity can be severe and require more extreme coping. Beyond this, we do not know at what point IWS might trigger fostering and migrating. However, we note that resettlement was documented in three papers. Migration, fostering, and resettlement may be less common in the context of IWS because they are generally viewed as responses to severe water issues that cannot be

ameliorated, e.g. in the case of permanent water contamination or severe water stress [40, 64], and those households may have already left. Households relying on IWS may perceive that they have a workable water supply and have adaptation strategies that do not require resettlement, migration, or sending a child to live with a grandparent or relative with a more stable water supply. The lack of migration-related themes may simply indicate a gap that may be filled with future research, perhaps related to limited interdisciplinary collaboration between population and migration scholars and the water research community, thus signaling an opportunity.

Most of the coping strategies found in this review come from literature that we classified as *Behavioral and Consumer Response Models* with few from *Hydrological and Engineering Modeling*. This gap in conceptual approaches represents an emerging opportunity for increased collaboration between the social and engineering sciences to generate transdisciplinary insights for IWS management, consistent with past calls [65]. Such approaches would support integrative and sustainable solutions to address adverse IWS impacts [9]. For example, the lack of any associations between IWS type and coping strategies does not necessarily mean that no meaningful relationships exist; future research may establish such connections.

4.5. Limitations

Our review and analysis face several limitations. First, IWS is a relatively nascent field of scholarship that, in lieu of standard terminology, appears in diverse literature as water rationing, rotations, outages, shutoffs, and other descriptors. If we narrowed our review to studies that explicitly named and described IWS, we would have missed a substantial number of studies. An unintended consequence of this more expansive search strategy, however, is that we systematically expanded the review to include adjacent fields of study (e.g. water insecurity) but may have missed other relevant fields. As a trade-off, we exclusively focused on piped water supplies, which is the main conceptualization of IWS. A more expansive approach could also examine water disruption associated with all water sources, but that was beyond the scope of this review. Our search strategy also limited the inclusion of grey literature and other non-peer-reviewed publications, which may have inadvertently excluded related literature (e.g. from water utility providers) or contributed to null coping findings (e.g. fostering or migration). Our search and inclusion criteria limited the pool of candidate studies to those in English and Spanish, which likely left out many geographies from our included studies. The lack of consistent terminology may have also biased our findings to particular geographical regions, although we tried to address this through our multidisciplinary co-author team representing most global regions. As the field of IWS matures, a future set of generally accepted terms may enable a more targeted search of the literature.

Second, most of the studies we reviewed were cross-sectional and local in scale, potentially obscuring longitudinal and regional/global dynamics. Additionally, dynamics such as seasonality [12] or informality (e.g. unregulated social or economic activities) [66] are less developed in IWS scholarship. Some of the studies we reviewed described IWS in fragmented and incomplete ways, which necessarily limits the conceptual robustness of our review. The geographical concentration of studies in predominantly low-conflict urban settings, such as Accra, Kathmandu, and Amman, may influence the relative frequency of observed coping strategies, while the limited representation of rural, remote, and conflict-affected urban settings may leave important coping responses insufficiently documented or appear less utilized.

Furthermore, differences in research focus and reporting practices across studies (i.e. many of which were not primarily about IWS or coping) may influence our results and is a caveat of the available literature. For example, there are likely additional public health studies where IWS contributed to adverse health outcomes, but was not a focal point of the study and thus not explicitly mentioned. Relatedly, the wide topical and methodological diversity of reviewed studies made a risk of bias assessment impractical, even with an interdisciplinary-friendly tool such as the Mixed Methods Appraisal Tool. Such a framework would potentially provide a misleading assessment of our review because many of the criteria related to study design—such as sample representativeness or handling of confounders—were frequently unrelated to the study's IWS context. These limitations clearly suggest gaps for future work but qualify what can be concluded from this review alone.

Nevertheless, we continue to see momentum in the IWS literature with increased recognition of human impacts and coping costs. There continues to be growing interest in these relationships with IWS as evidenced by recent studies in Ethiopia [67], Dominican Republic [68], Ecuador [69], and Malawi [28] that were all published after the conclusion of our analysis and highlight the urgency of addressing IWS-related user burdens in an increasingly water-scarce world.

4.6. Implications

This review reports on impacts and coping strategies adopted by water consumers. The range of behaviors and practices identified demonstrates how households are often required to be both proactive (e.g. purchasing and utilizing water filters for point-of-use treatment) and reactive (e.g. rationing supplies) in order to adapt to IWS. Most of the coping behaviors identified centered on the household's labor- and

trade-based strategies, which highlights opportunities for focused interventions. For example, households using water storage vessels and rainwater collection systems could be targeted with information and support on good hygiene practices, such as covering stored water, regularly and effectively cleaning storage containers, and treating water where appropriate. However, this review also highlights the many factors associated with IWS that are beyond the control of household members, including upstream energy disruptions affecting pump functionality, unpredictable supply schedules, and unreliable water quality. This demonstrates failure at the system level rather than the household level. It also points to opportunities for collective action, as households then bear ongoing responsibility for managing IWS through costly coping strategies. While certain household practices can mitigate immediate health risks and lessen other associated impacts, sustainable prevention ultimately depends on improving the reliability and predictability of piped water services.

Our integrated findings, therefore, have important implications for IWS providers. Water suppliers, whether formal utilities or community water associations, likely see the impacts and tradeoffs of IWS relative to continuous water supply, although these perspectives have rarely been systematically documented. In one of the few instances it has, in comparison to continuous water supply, evidence suggested likely impacts on pipe failures and meter integrity [70]. However, these costs and impacts have not been systematically documented as separate from the costs of running a continuous water supply system and are well beyond the scope of this study. Nonetheless, by better understanding the burdens of intermittency on their users, water providers could potentially improve services in several ways:

- Increase operational efficiency related to IWS, such as by shifting maintenance activities to low-demand times at night;
- Improve user experiences through better communication of intermittency schedules, which allows users to plan around outages;
- Attract government or NGO resources, such as grants or financing schemes, to address infrastructure maintenance backlogs and improve water availability.

5. Conclusion

In this review, we further unearthed the seemingly invisible impacts households and individuals bear and the coping strategies and adaptive management they must employ in order to live with IWS. We found that IWS was characterized by a range of overlapping service characteristics and should thus be understood as a multidimensional condition composed of duration, frequency, predictability, pressure, timing, seasonality, water quality, quantity received, and coping requirements. Our findings also highlight the need for consistent terminology to be used in future studies of IWS to allow more direct comparison across studies and settings. Given that impacts and coping strategies co-occur, finding integrative and sustainable solutions will address multiple impacts and burdens born by households simultaneously. Our findings identify several critical points at system and household levels that can mitigate IWS impacts, such as reinforcing energy infrastructure to minimize energy-related disruptions to water supplies, implementing safe storage to protect stored water quality between supply cycles, and improving predictability of IWS to reduce coping costs. As recent attention to IWS is growing in the scholarly and applied literature [71–73], future research is needed for IWS systems to identify modes of operation that minimize health impacts and the need for coping strategies.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.17604/2sfe-3v64. Data will be available from 01 November 2026 [74].

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References

[1] Galaitsi S E, Russell R, Bishara A, Durant J L, Bogle J and Huber-Lee A 2016 Intermittent domestic water supply: a critical review and analysis of causal-consequential pathways *Water* **8** 274
[2] Bivins A, Sumner T, Kumpel E, Howard G, Cumming O, Ross I, Nelson K and Brown J 2017 Estimating infection risks and the global burden of diarrheal disease attributable to intermittent water supply using QMRA *Environ. Sci. Technol.* **51** 7542–51
[3] Charalambous B and Liemberger R 2017 *Dealing with the Complex Interrelation of Intermittent Supply and Water Losses* (IWA Publishing)
[4] Farmani R, Dalton J, Charalambous B, Lawson E, Bunney S and Cotterill S 2021 Intermittent water supply systems and their resilience to COVID-19: IWA IWS SG survey *J. Water Supply Res. Technol. Aqua* **70** 507–20
[5] Ghorpade A, Sinha A K and Kalbar P P 2021 Drivers for intermittent water supply in India: critical review and perspectives *Front. Water* **3** 696630
[6] Totsuka N, Trifunovic N and Vairavamoorthy K 2004 Intermittent urban water supply under water starving situations. In: *30th WEDC Int. Conf.*
[7] UN News 2026 World enters era of global water bankruptcy (available at: https://news.un.org/en/story/2026/01/1166800)
[8] Andey S and Kelkar P 2007 Performance of water distribution systems during intermittent versus continuous water supply *J. Am. Water Works Assoc.* **99** 99–106
[9] Simukonda K, Farmani R and Butler D 2018 Intermittent water supply systems: causal factors, problems and solution options *Urban Water* **15** 488–500
[10] Vairavamoorthy K, Gorantiwar S D and Mohan S 2007 Intermittent water supply under water scarcity situations *Water Int.* **32** 121–32
[11] Kumpel E and Nelson K 2016 Intermittent water supply: prevalence, practice and microbial water quality *Environ. Sci. Technol.* **50** 542–53
[12] Broyles L M, Pakhtigian E L, Rosinger A Y and Mejia A 2022 Climate and hydrological seasonal effects on household water insecurity: a systematic review *Wiley Interdiscip. Rev. Water* **9** 1593
[13] Ercumen A, Gruber J S and Colford J M 2014 Water distribution system deficiencies and gastrointestinal illness: a systematic review and meta-analysis *Environ. Health Perspect.* **122** 651–60
[14] Price H, Ellis A and Quilliam R S 2019 The difference a day can make: the temporal dynamics of drinking water access and quality in urban slums *Sci. Total Environ.* **671** 818–26
[15] Zyoud S 2022 Mapping and visualizing global knowledge on intermittent water supply systems *Water* **14** 738
[16] Smiley S L and Stoler J 2020 Socio-environmental confounders of safe water interventions *WIREs Water* **7** e1438
[17] Ameyaw E E, Memon F A and Bicik J 2013 Improving equity in intermittent water supply systems *Water Supply Res. Technol. Aqua* **62** 552–62
[18] Klingel P 2012 Technical causes and impacts of intermittent water distribution *Water Supply* **12** 504–12
[19] Majuru B, Suhrcke M and Hunter P 2016 How do households respond to unreliable water supplies? A systematic review *Int. J. Environ. Res. Public Health* **13** 1222
[20] Belmeziti A 2025 Intermittent water supply: a literature review of causes, water availability and adaptation strategies *Water Environ. J.* **39** 260–74
[21] Venkataramanan V, Collins S M, Clark K A, Yeam J, Nowakowski V G and Young S L 2020 Coping strategies for individual and household-level water insecurity: a systematic review *WIREs Water* **7** e1477
[22] Achore M, Bisung E and Kuusaana E D 2020 Coping with water insecurity at the household level: a synthesis of qualitative evidence *Int. J. Hyg. Environ. Health* **230** 113598
[23] Altaf M A 1994 The economics of household response to inadequate water supplies *Third World Plan. Rev.* **16** 41
[24] Pattanayak S K, Yang J, Whittington D and Bal Kumar K C 2005 Coping with unreliable public water supplies: averting expenditures by households in Kathmandu, Nepal *Water Resour. Res.* **41** 2003WR002443
[25] Jeandron A, Saidi J M, Kapama A, Burhole M, Birembano F, Vandevelde T, Gasparrini A, Armstrong B, Cairncross S and Ensink J H J 2015 Water supply interruptions and suspected cholera incidence: a time-series regression in the Democratic Republic of the Congo *PLoS Med.* **12** 1001893
[26] Ercumen A, Arnold B F, Kumpel E, Burt Z, Ray I, Nelson K and Colford J M 2015 Upgrading a piped water supply from intermittent to continuous delivery and association with waterborne illness: a matched cohort study in Urban India *PLoS Med.* **12** e1001892
[27] Thomson P, Stoler J, Byford M and Bradley D 2024 The impact of rapid handpump repairs on diarrhea morbidity in children: cross-sectional study in Kwale County, Kenya *JMIR Public Health Surveill.* **10** e42462

[28] Niven C G et al 2026 Associations between water supply interruptions and water use, drinking water quality, child health, and caregiver stress in Peri-Urban Malawi *Environ. Sci. Technol.* **60** 2917–29
[29] Kenneson A, Beltrán-Ayala E, Borbor-Cordova M, Polhemus M E, Ryan S J, Endy T P and Stewart-Ibarra A M 2017 Socio-ecological factors and preventive actions decrease the risk of dengue infection at the household-level: results from a prospective dengue surveillance study in Machala, Ecuador *PLoS Negl. Trop. Dis.* **11** 0006150
[30] Thomson P, Pearson A L, Kumpel E, Guzmán D B, Workman C L, Fuente D, Wutich A and Stoler J 2024 Water supply interruptions are associated with more frequent stressful behaviors and emotions but mitigated by predictability: a multisite study *Environ. Sci. Technol.* **58** 7010–9
[31] Page M J et al 2021 The PRISMA 2020 statement: an updated guideline for reporting systematic reviews *bmj* **372** n71
[32] Digital Scholarship C 2024 Zotero [Computer software] (available at: www.zotero.org)
[33] Veritas Health Innovation 2024 Covidence Systematic Review Software (available at: www.covidence.org)
[34] Thomson P, Beresford M, Hossain J, Jacob C, Jordão C, Medina-Ramírez O, Neems S, Salcedo Serrano D, White D and Wutich A 2026 Addressing failing water systems: a qualitative protocol for intervention research on water insecurity *Int. J. Qual. Methods* **25** 16094069261432752
[35] Sen A 1982 *Poverty and Famines: An Essay on Entitlement and Deprivation* (Oxford University Press)
[36] Collins S M, Mock N, Chaparro M P, Rose D, Watkins B, Wutich A and Young S L 2024 Toward a more systematic understanding of water insecurity coping strategies: insights from 11 global sites *BMJ Glob. Health* **9** 013754
[37] Pahl-Wostl C 2007 Transitions towards adaptive management of water facing climate and global change *Water Resour. Manag.* **21** 49–62
[38] Scott C A, Meza F J, Varady R G, Tiessen H, McEvoy J, Garfin G M, Wilder M, Farfán L M, Pablos N P and Montaña E 2013 Water security and adaptive management in the Arid Americas *Ann. Assoc. Am. Geogr.* **103** 280–9
[39] Tompkins E L and Adger W N 2004 Does adaptive management of natural resources enhance resilience to climate change? *Ecol. Soc.* **9** 10
[40] Wutich A and Brewis A F 2014 Water, and scarcity: toward a broader anthropology of resource insecurity *Curr. Anthropol.* **55** 444–68
[41] Cohen J 1960 Kappa: a nominal scale measure of rater agreement *Ed. Psychol. Meas.* **20** 37–46
[42] Landis J R and Koch G G 1977 An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers *Biometrics* **33** 363–74
[43] World Resources Institute 2023 Aqueduct 4.0 Current and Future Country Rankings [Data set]. Aqueduct Water Risk Atlas (World Resources Institute)
[44] Abanyie S K, Ampadu B, Frimpong N A and Yahans Amuah E E 2023 Impact of improved water supply on livelihood and health: emphasis on Doba and Nayagnia, Ghana *Innov. Green Dev.* **2** 100033
[45] Abou S, Ali M, Wakponou A and Sambo A 2021 Impacts of climate change on domestic water and population's adaptation strategies in the Semi-Arid Region of Kenya *Handbook of Climate Change Management: Research, Leadership, Transformation* ed J M Luetz and D Ayal (Springer) pp 2177–200
[46] Achore M and Bisung E 2022 Do perceived inequalities in safe water access manifest in collective action? Evidence from urban Ghana *Health Promot. Int.* **37** daac151
[47] Ahile S I, Udoumoh E F and Adzande P 2015 Residents coping strategies with water scarcity in Makurdi Town, Nigeria *MJSS* **6** 100–8
[48] MdN A, Khatun F, MdS I, MdS H, Mou B H and Kumar P 2022 Assessment of household-level adaptation strategies to water stress in southwestern coastal Bangladesh: a counterfactual analysis *Water Policy* **24** 1516–40
[49] Abhijith G R, Naidu M N, Boindala S P, Vasan A and Ostfeld A 2023 Analyzing the role of consumer behavior in coping with intermittent supply in water distribution systems *J. Hydroinform.* **25** 1766–87
[50] Bender M V 2021 Water for Bongo: creative adaptation, resilience & Dar es Salaam's Water Supply *Daedalus* **150** 48–63
[51] Mendoza García C D, Navarro Gomez C J and Valencia Cortez A 2022 Drinking water consumption habits during intermittent service in Sector Riberas de Sacramento, Chihuahua, Mexico *Water Pract. Technol.* **17** 1992–2004
[52] Gaber N, Silva A, Lewis-Patrick M, Kutil E, Taylor D and Bouier R 2021 Water insecurity and psychosocial distress: case study of the Detroit water shutoffs *J. Public Health* **43** 839–45
[53] Emenike C P, Tenebe I T, Omole D O, Ngene B U, Oniemayin B I, Maxwell O and Onoka B I 2017 Accessing safe drinking water in sub-Saharan Africa: issues and challenges in South–West Nigeria *Sustain. Cities Soc.* **30** 263–72
[54] Klassert C, Sigel K, Gawel E and Klauer B 2015 Modeling residential water consumption in Amman: the role of intermittency, storage, and pricing for piped and tanker water *Water* **7** 3643–70
[55] Ngwenya B N and Kgathi D L 2006 HIV/AIDS and access to water: a case study of home-based care in Ngamiland, Botswana *Phys. Chem. Earth, Parts A/B/C* **31** 669–80
[56] Genius M and Tsagarakis K P 2006 Water shortages and implied water quality: a contingent valuation study *Water Resour. Res.* **42** W12407
[57] Avordeh T K, Salifu A, Quaidoo C and Opare-Boateng R 2024 Impact of power outages: unveiling their influence on micro, small, and medium-sized enterprises and poverty in Sub-Saharan Africa—An in-depth literature review *Heliyon* **10** e33782
[58] Aregu M B, Kanno G G, Ashuro Z, Alembo A and Alemayehu A 2021 Safe water supply challenges for hand hygiene in the prevention of COVID-19 in Southern Nations. Nationalities, and People's Region (SNNPR), Ethiopia *Heliyon* **7** e08430
[59] Mathee A et al 2021 Housing quality in a rural and an urban settlement in South Africa *Int. J. Environ. Res. Public Health* **18** 2240
[60] Pérez G T and Rodríguez D E A 2015 Comportamiento humano y prevención de dengue: estudio en barrios endémicos de Barranquilla, Bucaramanga y Armenia (Colombia *Campos en Ciencias Sociales* **3** 199–214
[61] Ercumen A, Billava N, Burt Z, Prasad S, Nayak N and Kumpel E 2026 Water Supply Continuity, Frequency, and Health Gains: Ten-Year Evidence from Hubli-Dharwad, India *medRxiv* (https://doi.org/10.64898/2026.07.23.26358804)
[62] Weston S L, Owino K and Masyula S N 2026 Spatial variation in intermittent water supply and the effect on consumer perceptions and practices in Machakos, Kenya [In Review]
[63] Brewis A, Jepson W, Rosinger A Y, Stoler J, Workman C L, Wutich A and Young S L 2025 Interacting water insecurity and food insecurity: recent advances in theory and application *Am. J. Hum. Biol.* **37** 70052
[64] Stoler J et al 2022 The role of water in environmental migration *Wiley Interdiscip. Rev. Water* **9** 1584
[65] Workman C L, Cairns M R, de Los Reyes F L and Verbyla M E 2021 Global water, sanitation, and hygiene approaches: anthropological contributions and future directions for engineering *Environ. Eng. Sci.* **38** 402–17
[66] Enqvist J et al 2022 Informality and water justice: community perspectives on water issues in Cape Town's low-income neighbourhoods *Int. J. Water Resour. Dev.* **38** 108–29

[67] Abeje E N, Fentie Cherie F and Yime A K 2025 Impact of household water storage practices on water quality: a case study of Debre Markos town, Ethiopia *J. Water Sanit. Hyg. Dev.* **15** 1007–22
[68] Brown H S, Gough K V, Kayaga S and Longley A J 2025 When coping strategies become the norm: household water insecurity in the Dominican Republic *Int. Dev. Plan. Rev.* **47** 175–97
[69] Lee G O, Sosa-Moreno A, Cuases G H, Giovannini A, Reinoso G, Schlesinger S B and Miller J D 2025 Use of the household water insecurity experiences (HWISE) scale to evaluate rural water delivery in small Ecuadorian communities *PLoS Water* **4** 0000471
[70] Christodoulou S and Agathokleous A 2012 A study on the effects of intermittent water supply on the vulnerability of urban water distribution networks *Water Sci. Technol. Water Supply* **12** 523–30
[71] Beresford M, Jepson W, Osborne-Gowey J, Dobbin K, Fencl A, González S R and Pierce G S 2026 secure, and affordable? The state of household water insecurity in California *J. Am. Water Resour. Assoc.* **62** e70127
[72] Charilaou M and Hussein H 2026 Measuring household water insecurity in intermittent supply systems: a context-sensitive index from urban Jordan *Urban Water J.* **23** 970–94
[73] Munyayi R, Swatuk L A, Mazvimavi D, Chiramba T and Mapani B 2026 Household water insecurity severity across urban areas with varying aridity levels in Sub-Saharan Africa: examples from Namibia *Water Secur.* **28** 100200
[74] Broyles L *et al* 2026 Data for: How intermittent piped water supplies impact households and coping strategies: A systematic review *Scholarship@Miami* (https://doi.org/10.17604/2sfe-3v64)