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ADVANCED REVIEW

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How should water affordability be measured in the United States? A critical review

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Abstract

The human right to water (HRTW) and sustainable development goals (SDG) emphasize that human well-being depends not just on the quality and physical accessibility of drinking water, but also on its economic accessibility. Despite this recognition, governments and academics alike have been hard-pressed to define and measure water affordability. In the US, affordability is no longer solely focused on utility cost-recovery models but equitable water access for individuals and households. How should water affordability be measured to represent this new focus? This question motivates the critical review presented here. We propose that household-centered affordability measures reflect the normative aims of internationally established frameworks such as the HRTW and the SDGs. Linking measurement to aims is essential to improve transparency and comparability across studies, and ultimately, to align measures with water access objectives. First, we characterize normative positions outlined in the HRTW and SDGs and identify defining features of water affordability. Second, we identify dominant definitions and measures of affordability, including novel approaches. Bringing the defining features of affordability to bear on existing measures enables us to identify several emergent debates in the literature where affordability measures could better incorporate the aspirations of the HRTW and SDGs. We conclude with recommendations on how to improve water affordability measurements, while recognizing the trade-offs between ideal measures and practical implementation.

This article is categorized under:

- Water and Life > Stresses and Pressures on Ecosystems
- Human Water > Value of Water
- Human Water > Rights of Water

KEYWORDS

affordability measures, human right to water, sustainable development goals, water affordability

1 | INTRODUCTION

In the US, water and sanitation access is neither equitable nor universal (Deitz & Meehan, 2019; Jepson & Vandewalle, 2016; Wescoat et al., 2007). Twenty-one million people in 2015 were provisioned by utilities that violated

health-based water quality standards (Allaire et al., 2018) and approximately half a million households lack adequate plumbing (Deitz & Meehan, 2019). Water and sanitation unaffordability is, in fact, rising among low-income households (Teodoro, 2019; Wutich et al., 2017). Affordability challenges have been documented in California (Christian-Smith et al., 2013; Onda & Tewari, 2021; Pierce & McCann, 2015), Michigan (Kay et al., 2018; Rockowitz et al., 2018), and the US–Mexico border in Texas (Jepson, 2014). Higher water costs and persistent poverty levels contribute to unaffordability, raising concerns that water affordability is a "burgeoning crisis" in the US (Mack & Wrase, 2017). Between 1990 and 2015, estimated average water and wastewater prices tripled in the US (Rubin, 2018). Increasing water costs result from the compounding influences of deteriorating water quality, degrading water infrastructure (Pierce et al., 2019), and higher levels of privatization (Bakker, 2010). Under-resourced communities served by smaller water systems are particularly challenged as the costs to produce water continue to rise (McFarlane & Harris, 2018). The affordability of water accessed by domestic wells is not studied, though 40 million people rely on them (Johnson et al., 2020).

Traditionally, communities and individuals facing unaffordable water have had little recourse but to rely on water-system level rate assistance if it exists (Onda & Tewari, 2021; Pierce et al., 2020). Between 2017 and 2019, however, the US Environmental Protection Agency (EPA) commissioned a revision of its federal-level water affordability standards (NAPA (National Academy of Public Administration), 2017), Baltimore and Philadelphia passed income-based billing for low-income households (Walton, 2019), and California proposed a low-income rate assistance program (SWRCB, 2019) as well as a tracking and monitoring tool for the human right to water (HRTW; Balazs et al., 2021). These efforts reflect a fundamental shift in affordability measurements from those that prioritize revenues to ensure that water systems can cover their capital, operational, and maintenance costs (cost recovery) to measurements that prioritize cost burdens for households and individuals. Though connected, the latter has received less attention in research and policy making.

Policy interventions require clearly defining and measuring water affordability. The most common approach to measuring affordability is as a ratio measuring the cost of water relative to household income. This ratio is compared against a specified benchmark to assess whether water is "affordable". The ratio method has several limitations, however, and researchers are developing improved measures for affordability in several OECD countries, including the US (García-Valiñas et al., 2010a, 2010b; Gawel et al., 2013; Martins et al., 2019; Teodoro, 2019). Current research in the US emphasizes financial costs for low-income households (Teodoro, 2019), critical evaluations of rate structures and equity (Beecher, 2020), and pragmatic policy interventions (Pierce et al., 2021). This research defines affordability beyond the cost-recovery paradigm and advocates for an equity focus on individuals and households. However, papers and policies alike rarely clarify the normative or guiding frameworks for deciding how to measure affordability. Meehan et al. (2020) capture this gap as an outstanding question for the field: "What are the best normative and critical ways to define and measure affordability?"

We argue that new norms and critical approaches to measuring household water affordability in the US should reflect the core tenets of the HRTW and the Sustainable Development Goals (SDGs). The HRTW and SDGs are well-established nonbinding commitments that many countries (including the US) have made to ensure safe and affordable water for individuals and communities. Both the HRTW and SDGs underscore normative aims of equity and sustainability. Interventions that aspire to effect sustainable and equitable outcomes require measures that incorporate these norms. Affordability is a core pillar of the HRTW (UN (United Nations), 2002). SDG 6, and the targets associated with it, operationalize the HRTW but also prioritize sustainability (UN, 2018; Gawel & Bretschneider, 2016). While neither the HRTW nor SDG 6 provides specific guidance on how to measure water affordability, norms established by the HRTW and SDGs can drive the selection of measures, for example, by articulating an essential needs volume of water to evaluate affordability. This can result in improved data collection to support more complex indicator development (e.g., Balazs et al., 2021; SWRCB, 2021a).

At a federal level, the US does not explicitly incorporate HRTW and SDG commitments in its water policy and regulations. Additionally, few studies in the US explicitly develop affordability measures that incorporate HRTW or SDG norms, due in part to a legacy narrative of affordability as a path to utility cost-recovery. Nonetheless, the HRTW and SDGs act as norm-setting frameworks across cities (Walton, 2019), states (Balazs et al., 2021), universities, foundations, and other institutions that reference the HRTW and SDGs as guidelines or aspirations for their ongoing work and new initiatives.

The goal of this article is to bring the normative content of the HRTW and SDGs to bear on how water affordability is defined and measured in the US. We conduct a critical review of the academic and gray literatures to evaluate existing affordability measures. We organize the review by asking: What are the defining features of water affordability in the dominant US policy landscape, and what advances do the HRTW and the SDGs offer? (Section 3); how is

affordability measured? (Section 4); and how do affordability measures relate to the defining features of affordability based on HRTW and SDG norms? (Section 5). In answering each question, we identify trade-offs between theoretical ideals and practical implementation of measures. Finally, we outline future research needs and recommendations for measuring water affordability (Section 6). Our work seeks to support researchers and practitioners who develop and use affordability measures with a view to monitor progress on the HRTW or the SDGs, especially in high-income countries.

2 | METHODS

We reviewed academic articles and gray literature reports for their definitions, measurements, and uses of water affordability and its variants. The papers in our review reflect a comprehensive database of studies and reports compiled over 6 years of work and research on affordability and the HRTW in California (Balazs et al., 2021; Supporting Information). We focused on studies from the US and other high-income countries that explicitly discussed water affordability and approaches to its measurement. Examples from these countries, cited throughout, represent a similar context to the US—where access to piped supply is high but affordability challenges persist. Water affordability measures typically focus on domestic water, that is, water used for consumption, hygiene, cooking, and cleaning; many metrics, however, include sewer charges in their water costs. While drinking water and sanitation are often jointly billed, we did not focus on broader sanitation affordability.

We did not consider studies on the cost of water treatment technologies or on water prices that did not explicitly discuss affordability. We excluded willingness-to-pay (WTP) for hypothetical water rates or water system upgrades, though WTP is often treated as a proxy for affordability when data are absent. Stated WTP methods are not a reliable basis for affordability policy or monitoring, because (i) hypothetical rather than actual payment cannot be monitored, and (ii) ability-to-pay and willingness-to-pay should not be conflated, especially for socially or economically vulnerable people. We also did not review survey-based studies on people's perceptions of whether their water was affordable (Koehler, 2018; Patel et al., 2010); this literature is valuable, but rarely includes quantitative measures of affordability (an exception is the water insecurity index literature; Jepson, 2014; Wutich et al., 2017). Finally, we did not review literature on affordability interventions (Pierce et al., 2021) or household responses to affordability (Meehan et al., 2020), as these are not expressly focused on measuring affordability.

3 | WHAT ARE DEFINING FEATURES OF WATER AFFORDABILITY?

The most intuitive understanding of water affordability is the ability-to-pay for the cost of water in relation to income (Hancock, 1993). We use the term "costs" rather than "expenditures" for households because it emphasizes both financial and nonfinancial burdens (UNICEF/WHO, 2021). Affordability as ability-to-pay, which treats water as one good among others in a household budget, is a concept rooted in microeconomics and public policy research (Kessides et al., 2009; Martins et al., 2016). How analysts choose to incorporate key affordability components into affordability measurements, such as nonfinancial costs of obtaining safe water, depends on social context and normative commitments. In this section, we characterize defining features of affordability that emerge from three norm-based contexts—US water policy, HRTW, and SDGs.

Since the 1970s, the dominant discourse on affordability in US water policy has emphasized the financial impacts of water service provision and water quality compliance on water systems. To the extent that the economic burden of water costs to households is considered, EPA has longstanding affordability guidelines for states disbursing Safe Drinking Water Revolving Funds (SDWRF). These guidelines direct states to (i) measure a Residential Indicator (RI) of water affordability as the ratio of water (or wastewater) bills to median household income (MHI) within water systems, and (ii) estimate a variety of financial capacity indicators of the community served by a water system (US EPA, 1997, 1998a). Conceptually, this focus has been less about the impact of a financial burden on households, and more about how households unable to afford the cost of safe water undermine a utility's financial capacity. As such, EPA's RI has historically represented an "overall assessment of general user ability to bear higher costs and thus the ability of the permittee [i.e., utility] to assure capital markets of its ability to repay borrowings needed to finance the required" operations (NAPA, 2017). Water safety upgrades add significantly to the cost of water services, so smaller water systems can face trade-offs between providing affordable water versus safe water.

As utilities face higher costs to provide safe water, water bills rise, exacerbating affordability problems for households, and challenging the traditional federal framework. More recently, the US EPA has proposed shifting the focus of the RI to better represent household affordability, especially those in lower-income brackets (NAPA (National Academy of Public Administration), 2017; US EPA, 2020a). Several states have gone beyond the SDWRF efforts and adopted the human right to safe and affordable water as a guiding framework for policy; these include California, Massachusetts, and Pennsylvania (Constitution of the Commonwealth of Massachusetts, n.d.; Eng. AB 685, ch. 524, 2012; The Constitution of Pennsylvania, n.d.). While the financial capacity of utilities remains critical to ensuring safe and affordable water, new individual and household-centered norms are needed to capture evolving policy trends (Pierce et al., 2020; SWRCB 2021a; Walton, 2019), research needs (Meehan et al., 2020), and community demands (Environmental Law Clinic, 2017).

The HRTW and SDGs offer an additional set of concepts and norms for the measurement of water affordability that can inform evolving trends in US water policy. Three characteristics of affordability can be inferred from the UN General Comment No. 15 (GC15) on the HRTW. First is a focus on the individual (or household). GC15 defines safe water as affordable if recurring and capital costs do not jeopardize a person's access to other essential rights (e.g., food or shelter; Salceda et al., 2013; UN, 2002, UN, 2005). Second, affordability cannot be dissociated from other dimensions of water access—physical accessibility, nondiscrimination, and information accessibility. Service disconnections consequent to inability to pay are thus a violation of the GC15's concept of HRTW. Third, the goal of nondiscrimination in GC15 demands a particular focus on vulnerable and historically marginalized groups.

The SDGs embed the HRTW within a broader framework of environmental sustainability (Kohlitz et al., 2016; UNDP, 2006), but how does this relate to affordability? In practice, (ecological) sustainability goals can add to household-level costs (and hence water affordability) through conservation or efficiency pricing, such as when utilities add fees to mitigate drought or reduce water leakages (Cooley et al., 2016). This tension exemplifies how household costs may fail to achieve HRTW aims while simultaneously ensuring ecological sustainability goals. A similar tension exists between household affordability and utility cost recovery, where utility cost recovery objectives result in unaffordable rates for households. In both examples, the HRTW and SDGs illuminate how multiple dimensions of affordability intersect in the household space. If water is highly affordable to a household's budget but it is unsafe, inaccessible, or unsustainably provided, this will have long-term impacts on household affordability and compromise sustainability. By considering norms of equity and sustainability jointly, affordability measures can make visible such challenges and resulting tradeoffs.

The links between financial and ecological sustainability and affordability are not made explicit in the development of affordability measures in the SDGs or HRTW. Definitions for physical access and quality populate the JMP indicators of drinking water service (Grigg, 2018; Kayser et al., 2013; WHO/UNICEF, 2019). However, a recent report on affordability measurements for SDGs highlights the need to link affordability to sustainability (UNICEF/WHO, 2021).

Four defining features of water affordability emerge from these normative frameworks, as illustrated in Figure 1: (i) affordability should reflect all costs—including financial and nonfinancial burdens relating to securing *safe* water; (ii) paying for water should not compromise the affordability of other essential needs; (iii) the burden of paying for water should be equitable and nondiscriminatory across socio-demographic groups; and (iv) water should be affordable while considering the long-term environmental or financial sustainability of water supply. While all four features conceptually refer to household-level access, research and policy frequently operationalize them at a community or utility scale.

4 | HOW IS AFFORDABILITY MEASURED?

This section reviews existing water affordability measures and classifies the extent to which these measures incorporate the four defining features of affordability in Figure 1, and throughout, we refer to relevant features in bold in parentheses (e.g. **Feature 1**). We first define components of affordability measures that map to Feature 1—water costs to households (Section 4.1) and arrears (Section 4.2)—and Feature 2, income or resources available to cover essential needs (Section 4.3). We then summarize commonly used (Section 4.4) and emerging affordability measures (Section 4.5). We conclude with an overview of Features 3 and 4—on equity and nondiscrimination (Section 4.6) and sustainability considerations (Section 4.7) in existing studies. These defining features are not frequently included in measures, but rather get incorporated through supporting analysis or implicit decisions about measurement. In each subsection, we first define concepts and then identify the ways they are measured and key caveats, with a focus on the US. Building on this,

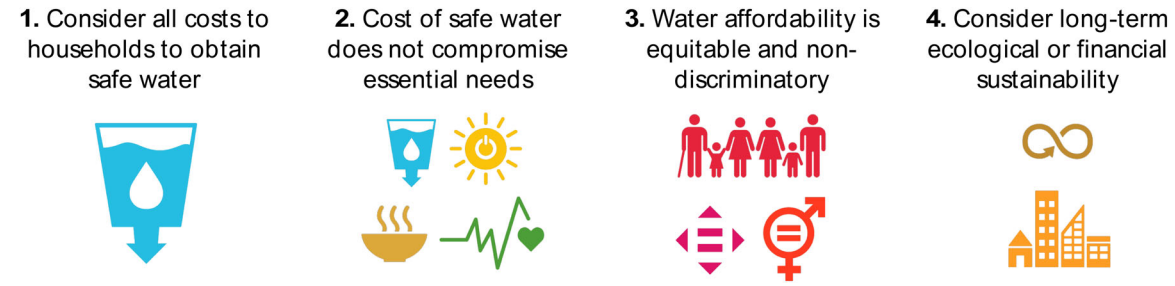


FIGURE 1 **Four defining features of water affordability.** Icons illustrate defining features of water affordability, drawing directly on commonly used SDG icons. Defining features derived from HRTW and SDG norms emphasize (i) *all costs of obtaining safe water* (SDG 6: Clean water and sanitation), (ii) *access to essential needs* (SDG 2, 3, 6, and 7: Zero hunger, good health and well-being, clean water and sanitation, affordable and clean energy), (iii) *equity and nondiscrimination* (SDG 1, 5, 10: No poverty, gender equality, reduced inequalities), and (iv) *sustainability of provision* (SDG 11 and 12: Sustainable cities and communities, responsible consumption, and production). Sustainability of provision (iv) includes financial sustainability of water supply

we indicate in Table 2 how the defining features described in Figure 1 might be reflected or incorporated into the measurement.

4.1 | Measuring household water costs

Any measure of affordability starts with an assessment of water costs for households (**Feature 1**). As noted above, we use the term costs for households to include nonfinancial costs, in alignment with HRTW literature. Recurrent financial expenditures include water bills, as well as replacement, avoidance, or coping costs, respectively. Capital costs include connection costs (for communities) and the purchase of household water treatment. Nonfinancial costs include the time and labor costs required to access or secure safe water. Below we summarize how the literature defines both types of costs for households before reviewing how these are incorporated into affordability measures.

The most common recurrent financial cost of water is captured in a household water bill. Bills are typically determined by service providers using rate structures, which depend on the existence of a meter and a pricing structure usually depends on the volume of water consumed. Subsidies, lifeline rates, fees (e.g., for wastewater and stormwater), and jointly-billed sewer costs can also contribute to a household's water costs.

Both financial and nonfinancial recurrent costs associated with the acquisition of water outside of water bills are more commonly studied in low-income countries, and include the time, labor, and financial costs to collect, treat, and store water from a variety of sources (Amit & Sasidharan, 2019; Burt et al., 2018; Narayanan et al., 2017; Soares et al., 2002). These costs are framed as coping or replacement costs needed to obtain safe water where the tap is inadequate (Amit & Sasidharan, 2019; Banerjee & Morella, 2011; Nganyanyuka et al., 2014). Bottled water is increasing globally as a primary water source (Cohen & Ray, 2018); other alternative water sources include vendors, kiosks, neighbors with connections, and shared public taps.

These alternatives do exist in the US, especially in low-income communities or during drought periods, but the US-based literature remains sparse. Whereas water bills are readily measurable in affordability metrics, the inclusion of coping or replacement costs is uncommon in industrialized contexts. Only two studies in our review evaluated the cost of vended water in an affordability context (Christian-Smith et al., 2013; Moore et al., 2011).

No studies in this review monetized household-level capital expenditures in the US. New connection costs are usually a one-time capital cost for households (Howard & Bartram, 2003; Jimenez-Redal et al., 2014; Mason, 2014; Narayanan et al., 2017) and communities (Balazs & Ray, 2014). Capital expenditures such as a new connection, household water treatment units, or upgrades to efficient appliances can be amortized over the expected lifetime to estimate the financial burden (Amit & Sasidharan, 2019; Pattanayak et al., 2005).

Measurement options are less clear for nonfinancial costs. No studies considering time costs were identified in the US. However, time spent collecting water can be estimated (Zuin et al., 2011) and then monetized by estimating lost wages associated with the time, for example, by multiplying the time spent accessing water by the hourly wage (Amit & Sasidharan, 2019) or 50% of the hourly wage (Pattanayak et al., 2005) where the prospects of employment are low.

TABLE 2 Water affordability measures and their link to the human right to water and sustainable development goals

Indicator type	Indicator or measurement	Scale(s)	Description	(1) All costs of water to households	(2) Essential needs	(3) Equity/ nondiscrimination	(4a) Sustainability of provision (cost recovery)	(4b) Sustainability of provision (environmental)	Select references
Ratio measures	Conventional affordability ratio	Household; community	Water/wastewater expenditures relative to income[a]	x			x		(Hutton, 2012; Mack & Wrase, 2017; Roaf et al., 2005)
	Potential affordability approach	Household; community	Water/wastewater expenditures for a specified quantity of water relative to income[a]	x	x	x	x	x	(García-Valiñas et al., 2010a, 2010b; Gawel et al., 2013; Martins et al., 2019; Miniaci et al., 2008b; Onda & Tewari, 2021)
	Ratio gap	Household; community	Measures the difference between conventional affordability ratio and a potential affordability ratio	x	x	x		x	(Martins et al., 2019)
	Affordability ratio at 20th percentile	Community	Water and/or wastewater expenditures for a specified quantity of water relative to 20th percentile income less other essential expenditures	x	x	x		x	(Teodoro, 2018)
	Capital expenditure relative to income	Household; community	One-time costs of capital expenses relative to income[a]	x		x	x	x	(Hutton, 2012)
	Full financial expenditure relative to income	Household; community	All financial costs (including water, storage, treatment,	x		x	x	x	(Hutton, 2012)

TABLE 2 (Continued)

Indicator type	Indicator or measurement	Scale(s)	Description	(1) All costs of water to households	(2) Essential needs	(3) Equity/ nondiscrimination	(4a) Sustainability of provision (cost recovery)	(4b) Sustainability of provision (environmental)	Select references
			on-site sanitation) relative to income[a]						
	Full financial and economic costs relative to income	Household; community	Full financial costs (as above) in addition to economic costs (e.g., time to collect and treat water, provide for sanitary needs, and economic value of time) relative to income[a] or expenditures	x		x	x	x	(Hutton, 2012)
Utility-induced poverty measure	Residual income approach	Household; community	Defines water as unaffordable when residual income[a] after paying for an essential amount of water is less than the poverty line.	x	x	x		x	(Gawel et al., 2013; Miniaci et al., 2008b)
	Double residual income approach	Household; community	Same as residual income approach, but also removes nonutility essential expenditures from income[a]	x	x	x	x	x	(Gawel et al., 2013; Miniaci et al., 2008b)
Labor burden	Hours minimum wage	Community	Number of hours at minimum wage required to afford water bill	x		x			(Teodoro, 2018)

Note: An "x" indicates whether a measure has the potential to address or incorporate a defining feature of water affordability identified in our review.

[a]Income can be household level reported income or an aggregate measure of income (e.g., median or across income deciles).

Several additional costs are not well-captured in the literature reviewed. Household water treatment costs and/or the creation and maintenance of groundwater wells are underrepresented in the literature, though an international study did estimate the "mitigating" costs of water boiling or and well-drilling (e.g., Nastiti et al., 2017). We found no US studies that captured the costs facing domestic well-owners in the US, whose water quality is not regulated or monitored (US EPA, 2020b).

4.2 | Measuring arrears and service disconnections

Another set of recurring costs relates to maintaining service and service disconnections. Economically vulnerable households may be unable to pay their water bill on time or at all (Beecher, 1994). Nonpayment of water and sewer bills results in arrears, with the risk of service disconnection. Steep reconnection fees can additionally burden households with high arrears; in Baltimore, households or community centers with high arrears have been placed on tax-liens (Colton, 2017). Disconnections after inability-to-pay are a violation of the HRTW (de Albuquerque, 2011), but persist as a disciplining practice, nonetheless. While international studies clearly document arrears, service suspensions, or temporary disconnections (Fankhauser et al., 2008), US-based work on disconnections and arrears is only recently gaining attention (Jones & Moulton, 2016; SWRCB, 2021b).

Several proposed metrics capture the burden of arrears and disconnections as components of affordability. These include the number of water shut-offs (Roaf et al., 2005), the percentage of households with delinquent bills (Raucher et al., 2019), the amount of arrears, and the frequency of customers with recurring payment problems (Fankhauser & Tepic, 2007). Few studies have quantified or measured these indicators (though see SWRCB, 2021c).

4.3 | Measuring resources available to households

Measuring affordability of the various costs discussed above requires comparison to the resources available to an individual/household Figure 1 (**Feature 2**). Most aggregate studies in the US use some form of gross income—the median income of an area or a low-income level (e.g., 20th percentile)—to capture available income. While this data is widely available, gross income over-estimates available income because not all income is disposable (e.g., income used to pay taxes). On the other hand, households may be low-income but have high wealth (e.g., retired homeowners). Using total expenditures to approximate available income can underestimate available income because expenditures exclude any unspent income. However, for low-income households, expenditures may be a more accurate measure of available income than reported income due to the variable or seasonal nature of lower-income jobs (Deaton, 1997).

More precise alternatives to gross income include disposable income (García-Valiñas et al., 2010a; Gawel et al., 2013; Smets, 2009), or disposable income less (modeled) estimates of essential expenditures (Teodoro, 2018). In the latter case, income and expenditure data together can indicate available resources and the relationship of water expenditures to other essential and nonessential spending (**Feature 2**).

4.4 | Ratio measures of affordability

To measure affordability as ability-to-pay, researchers typically assess the ratio of water costs to income (i.e., the affordability ratio) against a predefined threshold for affordability. Suggested thresholds range widely from 1.5% to 10% (Table 1). An affordability ratio greater than the predefined threshold indicates unaffordable water. There is no universally agreed-upon threshold, and selection of affordability criteria can greatly impact whose water is seen as (un)affordable (Gawel et al., 2013). The dominant thresholds are based on agency decisions in the US (e.g., EPA's 2.5% of median income for community water system affordability) or international standards (e.g., 3% income for households). The range of thresholds reflects different assumptions about what counts as a cost (e.g., drinking water only or also sanitation) and how to measure income (e.g., disposable or gross income).

Table 2 summarizes the conceptual relationships between existing measures of ability-to-pay and the defining features of affordability identified in Figure 1. The simplest ratio measure is the *conventional affordability ratio* (CAR), which measures water bills for average water use in a household or region as either a proportion of household income or of median income of a region (Hoque & Wichelns, 2013; Smith & Green, 2005). Measuring CAR at the MHI of an

TABLE 1 Affordability ratio thresholds and applications

Affordability ratio threshold	Water cost	Income type	Scale	References
1–2%	Drinking water	Median Household Income (MHI)	Nation; Water system; Census area	(Christian-Smith et al., 2013; Hanak et al., 2014; Pierce & McCann, 2015; US EPA, 1998a)
2%	Wastewater	MHI	Water system	(US EPA, 1997)
2.5%	Drinking water	MHI/Gross income[a]	Nation; Water system; Household	(EPA Science Advisory Board, 2002; US EPA, 1998a, 1998b)
3%	Drinking water and/or wastewater	Disposable or discretionary income[a]	Nation; Water system; Household	(García-Valiñas et al., 2010a; Reynaud, 2010; Sawkins & Dickie, 2005; UNDP, 2006)
4.5%	Drinking water and wastewater	MHI	Nation; Water system; Census area	(Mack & Wrase, 2017; US EPA, 1997, 1998a)
5%	Drinking water and wastewater	MHI	Nation; Household	(Villumsen & Jensen, 2014)
10%	Drinking water and wastewater	Discretionary income[a] (lowest income quintile)	Metropolitan area; Water system	(Feinstein, 2018; Teodoro, 2018)

[a]There is not a clear consensus in the literature regarding the use of gross income levels (income before taxes or expenditures), disposable income (gross income less taxes), or discretionary income (income less taxes and other essential expenses like housing). Income types reported in the table are illustrative of commonly indicated types in the literature.

area has been used to provide insight into the financial sustainability of a system (Table 2). However, this greatly underestimates the experience of low-income households and has led to critiques of the CAR at MHI (Environmental Law Clinic, 2017; EFAB, 2014).

Several advances to the CAR exist (Table 2). The *potential affordability ratio* (PAR) estimates costs for an essential-needs volume of water, variously referred to as an essential minimum quantity (Martins et al., 2019) or a lifeline level (García-Valiñas et al., 2010b). The estimated water bill for an essential-needs volume is divided by household income or by MHI of larger areas and compared to a threshold (Fankhauser & Tepic, 2007; García-Valiñas et al., 2010a; Gawel et al., 2013; Kessides et al., 2009; Miniaci et al., 2008a, 2008b). This approach avoids the problem of evaluating water affordability where actual expenditures on water reflect excessive consumption or under-consumption (i.e., self-rationing) among households—enabling incorporation of sustainability and equity concerns (**Features 2**, **3**, and **4**). The PAR has been critiqued as demonstrating problems of income deficit rather than a true water affordability problem (Gawel et al., 2013) because in an area with the same water rate, household affordability ratios will differ only by their income. However, applied in multiple water services areas (where water costs may vary), the PAR can capture unaffordability driven both by poverty and high-water costs (Goddard et al., 2021). The difference between a PAR and a CAR for a household has been introduced as the *ratio gap metric* to indicate the difference between what a household should pay for essential-needs water and what they actually pay (Martins et al., 2019).

Hutton (2012) suggests, but does not calculate, a set of ratio measures for nation-scale affordability tracking in a HRTW context. These measures advance the PAR and CAR by emphasizing the full financial and nonfinancial costs of water (Table 2), as well as one-time costs such as construction costs. Such costs are likely important for domestic well users who incur larger capital costs or ongoing treatment costs.

Davis and Teodoro (2014) introduced a variant of the PAR—the AR_{20}—to indicate whether water and sewer costs are unaffordable after other needs have been met for low-income households. In AR_{20}, discretionary income is estimated by removing modeled expenditures for food, housing, taxes, medicine, and home energy from the 20th percentile income of metropolitan regions served by large utilities serving more than 3300 people. AR_{20} requires analysts to

predetermine a set of normative criteria—an essential-needs amount of water and a minimum budget for other essential goods.

4.5 | Emerging affordability measures

In addition to the various affordability ratios discussed above, alternative measures of affordability focus on how water costs relate to poverty levels or low-income wages. *Utility-induced poverty* defines water and other utilities as unaffordable if households fall below the poverty line after paying for all utilities (Miniaci et al., 2008b). This work extends water affordability ratios to reflect a household's ability-to-pay for all utilities, including heat, gas, and electric (Fankhauser et al., 2008; Fankhauser & Tepic, 2007; Mohlakoan & Dugard, 2017). The utility-induced poverty concept can be applied with the *residual income approach* (RIA) method (Gawel et al., 2013; Miniaci et al., 2008a, 2008b), where water is unaffordable when the cost of water puts a household's residual income below the cost of essential-needs expenses, sometimes interpreted as the poverty line. Connection costs can be included in the bundle of essential needs (Kessides et al., 2009). Like the affordability ratio, the RIA was first proposed in the housing affordability literature (Kutty, 2005; Stone, 1990).

While similar to AR_{20} in its attention to lower-income levels and essential needs, RIA differs from other metrics reviewed in that the focus is on the difference between income that households have and what they need to afford essential needs *after* paying for water. Where the essential-needs income level is set at the poverty line in the RIA, as in Miniaci et al. (2008b), households earning below poverty line incomes have unaffordable water by definition. Where households are above the poverty line, the RIA can help categorize households as over-consuming (using more than essential-needs water) or under-consuming (using less than essential-needs water; Gawel et al., 2013).

Davis and Teodoro (2014) proposed calculating the *number of hours worked at minimum wage (HM)* to capture the time it would take someone working at minimum wage to earn the income necessary to pay their water bill. The authors suggest that an affordability challenge exists if HM is greater than 8 h (or a full day of work in the US). In the US, this approach is easy to calculate because minimum wage levels are readily available by state or city (Teodoro, 2018, 2019). However, reframing the question of ability-to-pay as one of the reasonableness of labor time required to pay does not directly address ability-to-pay. While in theory minimum wage is enough to support cost-of-living in an area, the wage is often set so low that households living on minimum wages rarely have adequate income.

4.6 | Equity analyses for affordability

Affordability in the human rights context requires a special focus on the most vulnerable people and households (UN, 2002). Nondiscrimination is a requirement of implementing any human right, and it is possible for measures of affordability to represent this condition (**Feature 3**). These norms are primarily considered through the selection of income levels in affordability measures and supplemental equity analyses. Low-income groups are a focal point for PAR and RIA measures (Table 2). Most commonly, affordability ratios are estimated for households earning at the lowest income quintiles (Gawel et al., 2013; Reynaud, 2006; Teodoro, 2018) or across all income levels available (Martins et al., 2016; Sawkins & Dickie, 2005; Vanhille et al., 2018). A focus on the bottom income quintile has gained traction in US policy discussions (e.g., CPUC, 2019; Feinstein, 2018; NAPA, 2017).

Supplementing affordability measures with additional indicators of economic or social vulnerability can incorporate further equity concerns. Raucher et al., 2019 summarize a set of such analyses in the US, including percentage of households below the federal poverty level or supplemental poverty measure, percentage of households below the living wage, percentage of household income spent on shelter costs, and percentage of households receiving public assistance. Mack and Wrase (2017) analyze census tracts "at risk" of facing unaffordable water and sewer costs relative to MHI by evaluating differences in social and economic variables, such as the percentage of households receiving public income assistance, on food stamps, or without health insurance. Other "high risk" categories important to ensure nondiscrimination in water access and affordability include housing type (e.g., size, unit type; Martins et al., 2019; Pierce & Gonzalez, 2017), ownership of assets (e.g., household owner or renter), renters who do not pay direct bills (Environmental Law Clinic, 2017), welfare status (Mangold et al., 2014), gender, race/ethnicity (McDonald & Jones, 2018), and households served by smaller water systems (Goddard et al., 2021; McFarlane & Harris, 2018) or different institutional forms of water providers (Onda & Tewari, 2021).

No quantitative studies of affordability measures included gender, despite qualitative research indicating its importance in an international context (Carolini, 2012; Mohlakoan & Dugard, 2017).

4.7 | Sustainability considerations in affordability measures

Two elements of sustainability (**Feature 4**) are critical to consider for affordability: environmental sustainability and the better studied area of financial sustainability. The financial sustainability of a system has direct and indirect impacts on household affordability. Financial sustainability is partially a function of the stability and predictability of revenue (Blanchard & Eberle, 2013), which, in the US, usually derives from consumer rates and fees (as opposed to taxes or transfers). Low financial capacity of the water system (i.e., the community) can lead to unsustainable operations that fail to meet water quality standards, thereby increasing the burden of unaffordability for households forced to purchase bottled water, treat tap water, or foot rate hikes to cover compliance costs (Jones & Joy, 2006). Indicators of financial sustainability largely focus on the credit availability, debt, and revenue streams of utilities as they relate to the cost of sourcing, treating, and distributing water (Davis & Teodoro, 2014; Raucher et al., 2019). Representing median-household affordability (the RI) has been EPA's attempt to link household affordability with water system financial sustainability.

The SDGs clearly embed the aspiration for safe and affordable water within a broader framework of environmental sustainability (Kohlitz et al., 2016), but as Gawel and Bretschneider (2016, 2017) emphasize, this criterion of sustainability is rarely connected to normative aims for the HRTW or affordability measures. Yet environmental sustainability is relevant to household affordability in numerous ways, most directly through how affordability changes in response to conservation rates, environmental risks to supply, or inefficient infrastructure (**Feature 4**). Affordability measures focused on essential-needs volumes of water aspire to separate luxury water uses from affordability assessment and therefore incorporate SDG-compatible norms of conservation. Conservation rates may burden large households with higher essential-needs water use. Disaggregating ability-to-pay with respect to the equity implications of rate design can illuminate whether affordability and conservation goals are at odds. For example, Martins et al., 2013 compare the cost of acquiring essential-needs water to first-tier water rates (Martins et al., 2013). Households with less-efficient appliances or leaking infrastructure use more water and thus incur higher bills (Bakker, 2010; Environmental Law Clinic, 2017), though no studies evaluate this phenomenon and its impact on affordability, despite evidence that this is an area critical for policy intervention (Pierce et al., 2021). Bottled water is unsustainable in terms of greenhouse gas emissions (Goddard, 2019; Reygadas et al., 2014) and plastic waste. Including bottled water costs in measures makes visible the high environmental price of broader failures to address community water quality problems (Moore et al., 2011).

5 | AREAS OF DEBATE FOR MEASURING WATER AFFORDABILITY AND REFLECTING HRTW AND SDG NORMS

This section discusses ongoing debates related to implementing the affordability measures introduced in Section 4. We make visible the judgments, trade-offs, and data challenges inherent in applying affordability measures to reflect HRTW and SDG aspirations. These debates include how to: count the full costs to obtain safe water (Section 5.1), adequately capture resources available to households (Section 5.2), measure essential-needs water (Section 5.3), determine the criteria for affordability (Section 5.4), account for the spatial and temporal scale and scope of the study, as well as (Section 5.5) how measurement relates to broader norms of social equity/nondiscrimination (Section 5.6) and the sustainability of provision (Section 5.7). Throughout, we identify how analysts might navigate practical data constraints *and* incorporate the normative aims of the SDGs and HRTW. In Section 6, we distill this overview into a set of recommendations as they relate to the four defining features of affordability.

5.1 | Counting all costs of safe water to households

From an HRTW perspective, all costs of safe water, inclusive of sanitation and hygiene, should be incorporated into affordability assessments (**Feature 1**). In both international and national studies, however, drinking water is often treated separately from sanitation, and recurrent costs outside of water bills, such as bottled water, are less commonly

included (but see Komarulzaman et al., 2017; Nastiti et al., 2017; Walter et al., 2017). Costs associated with alternative water sources (relative to a household's primary source) and coping costs for treating poor water quality directly implicate the HRTW and SDGs. Bottled water costs have been included in affordability ratios in California (Christian-Smith et al., 2013; Moore et al., 2011), reflecting how affordability can capture coping costs. We acknowledge that many bottled water purchases are "lifestyle" purchases regardless of tap water quality. However, where water quality fails regulatory standards, it is particularly important to include bottled water expenses in affordability measures. Bottled water consumption is prevalent among low-income households that distrust their water quality (Javidi & Pierce, 2018), leaving it unclear whether purchases are based on perceived or truly unsafe water. Cost of arrears has been estimated as "water debt" in California during COVID-19 (SWRCB, 2021b) and disconnections have been quantified in several areas (Onda & Tewari, 2021; Swain et al., 2020). Quantification of nonpayment rates may not always signify unaffordability, but for lower-income households such a metric is likely to indicate unaffordability. Furthermore, nonpayment across income levels might be a useful indicator of broader risks to the financial sustainability of water service providers that rely on payments to operate (**Feature 4)**.

Costs for water treatment or well maintenance and nonfinancial costs for households remain under-studied in the US. We found almost no research on domestic well (water systems with fewer than 15 connections and private wells) costs in the US, though approximately 12% of the US accesses water this way (Johnson et al., 2020). It is likely that households using domestic wells face greater time, effort, and treatment costs to maintain safe drinking water, given documented microbiological and chemical contamination (Heaney et al., 2013; Murray et al., 2018; Stillo & Gibson, 2017). At a minimum, studies in the US context should aim to address open questions about the time costs in households that have lost, or that never had, piped water access, as well as evaluate the full scope of potential costs for domestic well users.

Many costs beyond the water bill are well described in the international affordability literature, for example, collection, pumping, storage, treatment, and purchase of water from nonutility sources (Pattanayak et al., 2005). However, there is little agreement on how or if alternative and coping costs should be monetized and included in affordability measures. The broader literature has no consensus on whether to monetize time at all, and, if monetization is desirable, whether to value time at the household's wage, the minimum wage, or a fraction of the wage (see Ahuja et al., 2010; Pattanayak et al., 2005).

Investigation into recurrent costs beyond the water bill should be a priority area for future affordability research given evidence that disconnections, alongside affordability, are associated with psychosocial stress and distress (Gaber et al., 2020; Jepson, 2014; Kay et al., 2018). Hutton (2012) suggests incorporating these costs into a single affordability ratio. However, showing these costs as supplemental measures may be useful where monetizing nonfinancial costs is controversial.

5.2 | Capturing resources available to households

A defining feature of affordability is that water is not affordable if it must be paid for at the expense of other essential needs like adequate shelter and food (**Feature 2**). The denominator of an affordability ratio or the income variable in the RIA should represent the amount of money a household has available to spend on the water. A small but important set of studies in the US demonstrates that many households are paying for water that they cannot afford. Families may sacrifice other essential needs—like rent, transportation, and healthcare—before they forgo paying for water (Colton, 2017; Rockowitz et al., 2018). These precarious trade-offs between high-cost water and essential needs are well-known in international water research and are likely to exacerbate existing economic distress (Mason, 2014). An HRTW-focused affordability assessment would therefore include data on what a household has available to spend, its income, and what the household spends on water and other essential expenditures over time.

An emphasis on disposable or discretionary income in measures improves upon the limitations of gross income as a proxy for available resources. However, analysts must prespecify an income level for evaluation so that high-income households with high expenditures (and thus low disposable income) are not identified as facing unaffordable water. AR_{20} conceptualizes affordability as the impact of water bills on a low-income household's spending after they have paid for shelter, food, taxes, and so forth. The use of AR_{20} can be problematic in broader applications, however, because the bottom fifth of the income distribution may not be low-income when the spatial scale of study is a small water system serving a high-income area. Recent applications of the method in smaller water systems resulted in negative affordability ratios when modeled expenditures for essential needs were removed from income (Jensen et al., 2019). This

result suggests that where expenditure and income data are both available, the residual income approach might provide a better measure.

The broad assumption in both AR_{20} and RIA is that, after accounting for expenses toward other essential needs, we can estimate the affordability of water relative to residual, or discretionary, income. However, removing other essential expenditures from the equation does not indicate whether households avoid trade-offs with other expenses. Some evidence suggests that evaluating water bills as a ratio of discretionary income may assume more about household spending than we know. Cory and Taylor (2017) model the internal structure of spending budgets over time in the US Consumer Expenditure Survey for different income levels and demonstrate that households respond to increased water costs by cuts in their discretionary spending, but also for health care and, in some cases, food. If water and sewer bills at <10% of discretionary income are considered affordable (Teodoro, 2018, 2019), households could still be decreasing spending on other essential needs. This is generally true of all ratio measures. However, an increased focus on modeling discretionary income may be impractical where data quality is poor or incomplete if the gains in interpretability about household trade-offs are not clear (UNICEF/WHO, 2021). More granular research is needed to clarify which purchases and costs are deemed essential both in HRTW and SDG context, and ultimately what trade-offs households make to pay for water.

5.3 | Measuring essential-needs water

As a human right, essential-needs water should be affordable, and therefore measuring average consumption—especially in high-income areas with landscaping—is inappropriate for affordability assessments. Ratios quantifying the cost of average household water use risk under- or over-estimating unaffordability (Gawel et al., 2013). Underestimation of unaffordability arises because households may only consume what they can afford—the problem of "paid but unaffordable" (Colton, 2017). Alternatively, overestimating unaffordability can occur where "luxury" water use like landscaping is common practice and the frequent focus of conservation efforts. Both self-rationing and nonessential water consumption justify attention to essential-needs volumes in affordability measures (**Feature 2**). Using essential-needs water volumes in aggregate (e.g., system or region level) measures can also support identification of inequities in affordability across regions for the same (or multiple) essential volume(s) (**Feature 3**). For example, comparing the costs to consume essential-needs volumes demonstrates that affordability is regressive across income levels within municipalities and water systems (García-Valiñas et al., 2010b; Martins et al., 2016).

Determination of an essential-needs volume is a critical step with several trade-offs to consider. The literature suggests multiple approaches: (i) determining essential-needs water from demand functions, namely the Stone–Geary function (García-Valiñas et al., 2010b; Sebri, 2015); (ii) estimating essential water requirements for universal norm-setting (Gleick, 1996; Howard & Bartram, 2003); or (iii) deriving location-specific estimates based on "reference budgets"—or the minimum amounts needed for washing, cooking, hygiene, and consumption (Feinstein, 2018; Vanhille et al., 2018; WHO/UNICEF, 2019). Where essential-needs volumes vary by location or family size, a matrix of scenarios can be evaluated. Comprehensive metrics should also include essential needs for sanitation and sewer services.

The volume of water selected to capture essential needs is sensitive to scale and underscores a potential tension between defining **Feature 2** (essential needs) and **Feature 3** (equity). For example, in both rate design and affordability measures, if an essential-needs volume is selected *per household* as opposed to *per individual*, this can disadvantage large households, which may consume less water per person but larger total volumes. Because low-income households tend to be larger (Environmental Law Clinic, 2017; García-Rubio et al., 2015; García-Valiñas et al., 2010b), such households may be disproportionately burdened if the essential-needs (or lifeline) block is set at an inadequate volume in water billing. For instance, the essential-needs water policy in South Africa in the early 2000s guaranteed households 6 kL per month for free, which was intended to provide 25 L per person per day. This effort underserved larger households, who faced high water bills after exceeding the minimum volume (Smith & Green, 2005). Water needs also vary by region and infrastructure conditions, suggesting a geographic component to consumption that a single essential needs volume overlooks (Environmental Law Clinic, 2017; Vanhille et al., 2018). One way to address these issues is to evaluate affordability for a range of essential-needs water levels, as this might better capture the diversity of water needs and potential risks to environmental sustainability of provision. This is not common in the literature; researchers face challenges obtaining rate data for different levels of consumption, and single affordability thresholds are more convenient for policymakers.

5.4 | Determining criteria for affordability

What counts as affordable is dependent on the socioeconomic context, as well as on social and political values (Page, 2005; Teodoro, 2018). In practice, what *gets counted* as affordable depends on the choice of measure and corresponding evaluation criteria, for example, affordability thresholds (Table 1). In the US, EPA's 2.5% threshold for drinking water affordability derives from an assessment of what median-level households pay for other basic expenses (based on Consumer Expenditure Surveys), the average replacement costs, and a motivation to minimize permitted exemptions to the Clean Water Act (US EPA, 1998b). By comparison, surveys in the UK motivated a 3% threshold as an affordability standard based on the average burden for households in the lower three income deciles (Fitch & Price, 2002)—a number that has been circulated regularly in the international literature (Smets, 2009). The EPA's stance on representing water affordability as up to 2.5% of the MHI has garnered criticism that this benchmark is too high for lower-income households. Nonetheless, this has been a standard used in recent studies emphasizing household affordability (Mack & Wrase, 2017), despite its more common use in assessing system-level affordability (Janzen et al., 2016). In state policy, however, lower affordability thresholds are common. For example, in California, the State Water Resources Control Board has used a threshold of 1.5% MHI to provide financial aid to lower-income water systems (SWRCB, 2018). Careful selection of thresholds or use of multiple thresholds should be explored and published to demonstrate how affordability criteria impact results.

How criteria for affordability thresholds came into existence in the first place is less scrutinized (Rubin, 2001), and while threshold-based measures have been questioned (NAPA, 2017), few alternative criteria currently exist. Some researchers (Goddard et al., 2021; Sawkins & Dickie, 2005) present the distribution of results and interpret affordability as a spectrum from more to less affordable, without normatively declaring water to be "affordable" or "unaffordable" at a specific threshold. Others have proposed a matrix evaluating the number of people paying above 3% of household income and below 1% of household income, disaggregated by different consumption and income levels (Barraqué & Montginoul, 2015). All of these approaches can support monitoring affordability over time in situations where a consensus does not exist on what counts as affordable. While the RIA avoids the challenge of determining an affordability threshold, one must ask "At what poverty threshold should utility-induced-poverty indicate an affordability challenge"? In short, the normative determination of affordability criteria applies across all measures.

Yet none of these approaches fully captures the affordability of all costs to households. Additional financial dimensions of affordability—such as disconnection costs, increasing reliance on bottled water, and excessive consumption due to inefficient appliances or infrastructure—could be modeled and incorporated into ratios to evaluate the benefit of some criteria over others. Affordability for nonfinancial burdens like time spent or disconnections incurred requires more research into what criteria should indicate unaffordability.

5.5 | Identifying the appropriate scale and scope of study

The HRTW considers the household as the relevant scale to evaluate affordability (Gawel et al., 2013; Jepson & Vandewalle, 2016; Martins et al., 2016; Vanhille et al., 2018). Yet household-level data on water costs and expenditures are not uniformly collected by governments or water utilities. Broader-scoped efforts tend to rely on data aggregated to a higher spatial scale. For example, affordability has been measured at the national scale for HRTW monitoring (Smets, 2017) or at the water system scale in the US to disburse SDWRF to assist systems with water quality standard compliance (US EPA, 1998a). Aggregate measures obscure the underlying variability of water costs and incomes within a population. This critique has been addressed in part where studies stratify aggregated affordability data by income groups and household types (OECD, 2009; Sawkins & Dickie, 2005) within census tracts (Mack & Wrase, 2017), within municipalities (García-Valiñas et al., 2010a), or within water systems (Goddard et al., 2021; Teodoro, 2018). One way to resolve the tension between a desire for a fine-grain scale of analysis and common data limitations is to first evaluate affordability at the water system or municipality, to align measures with the scale of policy interventions. Results can then be further disaggregated by income levels or other variables of relevance to reflect study priorities.

Affordability is commonly evaluated using cross-sectional data; fewer studies have included a temporal dimension using predictions about future water rates and incomes (Fankhauser & Tepic, 2007; Mack & Wrase, 2017). Repeat studies of affordability metrics over time have shown that US water rates are rising steadily (Teodoro, 2018, 2019). Rate increases over time are driven by many factors, including environmental change, and deteriorating infrastructure (**Feature 4**). Evaluating affordability over time can enable monitoring of the HRTW (e.g., Balazs et al., 2021), on the one hand, and evaluation of policy interventions related to affordability (Pierce et al., 2021), on the other.

5.6 | Evaluating equity and nondiscrimination

Existing studies have primarily incorporated equity and nondiscrimination concerns by evaluating affordability for low-income households, analyzing supplemental measures of social vulnerability, or disaggregating affordability results (Section 4.6). Inequities along lines of race/ethnicity are persistent in access to environmental benefits and essential needs in the US and reflect an important research direction to investigate nondiscrimination in affordability assessments. Racial inequities persist within lower-income census tracts (Mack & Wrase, 2017) demonstrating the need for better representation of racial/ethnic disparities even within affordability measures that capture low-income households. Disconnection patterns disproportionately affect communities of color (Sabourin, 2016; Swain et al., 2020). Recent work on a representative sample of US water systems found a weak correlation wherein a higher percentage of Hispanic households within a water system was correlated with more affordable water (Teodoro, 2019). It is unclear if the lack of a strong relationship between race and affordability in these studies reflects a truly weak relationship, or the limitations of affordability measures that only capture water costs from a water bill.

Unsafe water can compound affordability issues, bestowing a "joint burden" of low water quality and high unaffordability on communities and households (Balazs & Ray, 2014). More affordable water could be coupled with worse water quality if utilities are not adequately treating water. In such situations, quantifying coping costs and their equity implications is critical. Allaire et al., 2019 found that Tier 1 health risk violations (i.e., requiring immediate action by utilities) are associated with high increases in bottled water sales in non-rural, low-income communities. Hispanic and Black households disproportionately drink bottled water over the tap water compared to white households (Javidi & Pierce, 2018). Bottled water is more expensive than tap water. More work is needed to account for the cost burden of reliance on bottled water and to elucidate the relationships among water affordability, water quality, and race/ethnicity. Studies could incorporate projected bottled water costs into affordability measures in service areas known to have inadequate tap water quality and disaggregate results by race/ethnicity.

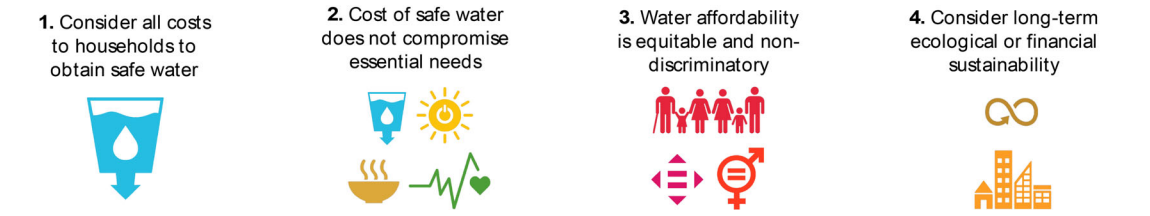
5.7 | Incorporating sustainability of provision

Historically, financial sustainability has been the primary emphasis of affordability measures in water policy as compared with environmental sustainability (**Feature 4**). Beyond affordability measures for the MHI in an area, identifying the population facing unaffordable water could be a useful supplement to household affordability assessments to signal potential financial sustainability concerns for water systems. This could be indicated by the number of households that have adequate income such that water bills are no greater than a prespecified affordability threshold (Christian-Smith et al., 2013; Feinstein, 2018). Hoque and Wichelns (2013) suggest that the lowest consumption level in a rate structure should be affordable and adequate, but higher consumption levels should prioritize cost recovery goals. The use of rate design as an affordability intervention is well documented (Pierce et al., 2021), and household-level studies examining the role of rates as relates to affordability should aim to concurrently address the tension between sustainability of provision and equity (**Features 3** and **4**).

Affordability measures can and should better incorporate considerations for the environmental sustainability of provision to align household affordability concerns with HRTW and SDG goals. Already scholars are carefully considering essential-needs water volumes, as discussed above. Critical system upgrades necessary to respond to environmental hazards (e.g., fire, drought) can also result in higher costs for households (Cooley et al., 2016). Studies designed to compare water affordability over time could elucidate the role of environmental change in affecting household affordability through rate hikes. This review did not include studies on the affordability of adopting new technologies in water systems; such work compares affordability before and after upgrades (Jones & Joy, 2006). Relatedly, EPA's affordability ratio for sewer and wastewater (RI) incorporates the projected costs of wastewater and combined sewer overflow control for compliance (US EPA, 1997). Such approaches could guide studies looking to investigate future costs for environmental, in addition to regulatory, cost changes.

6 | RECOMMENDATIONS

The ongoing debates reviewed in Section 5 demonstrate the numerous ways that existing affordability measures can, and to some extent already do, incorporate the HRTW and SDG norms. In this section, we summarize recommendations for improving affordability measures based on the defining features of affordability and ongoing debates (Figure 2).



Area of Debate	*Recommendation*
5.1	Incorporate bottled water and household water treatment costs
5.1	Characterize costs for households not served by water systems
5.4	Expand criteria for affordability beyond financial costs

Area of Debate	*Recommendation*
5.2	Identify trade-offs that households make to pay for water
5.3	Use range of essential needs water volume(s)
5.3	Identify equity of essential-needs volumes in water rates

Area of Debate	*Recommendation*
5.5	Ensure spatial and temporal scale of Measure does not obscure inequities
5.6	Disaggregate by household size
5.6	Explicit focus on low-income levels
5.6	Explicit focus on race/ethnicity

Area of Debate	*Recommendation*
5.3	Use range of essential needs volume(s)
5.5	Evaluate affordability over time
5.7	Evaluate impact of water inefficient appliances and infrastructure
5.7	Evaluate impacts from environmental and financial change

FIGURE 2 **Summary of recommendations for incorporating HRTW and SDG norms into affordability measures based on defining features of affordability and ongoing debates in affordability research.** Defining features derived from HRTW and SDG norms emphasize (i) *all costs of obtaining safe water* (SDG 6: Clean water and sanitation), (ii) *access to essential needs* (SDG 2, 3, 6, and 7: Zero hunger, good health and well-being, clean water and sanitation, affordable and clean energy), (iii) *equity and nondiscrimination* (SDG 1, 5, and 10: No poverty, gender equality, and reduced inequalities), and (iv) *sustainability of provision* (SDG 11 and 12: Sustainable cities and communities, responsible consumption and production). Below each icon, we list recommendations emergent from the critical review, to improve affordability measurement in the context of HRTW and SDG norms

While the international literature is emphatic about capturing the full costs of water to households, US-based affordability measures rarely capture these costs. Not *all* coping costs identified in the broader literature are necessarily applicable to the US case, but their inclusion should be considered and evaluated to reflect HRTW and SDG norms. For example, where water quality is known to be poor, affordability studies should augment their cost estimates with the added costs of household treatment and/or the use of bottled water (**Feature 1**). To determine whether water quality is indeed poor, data could be incorporated using health-based water quality violations (Allaire et al., 2019), boil alert notifications, state-level water quality monitoring data, or targeted sampling efforts. Characterizing recurrent, non-water bill costs is particularly important for households not served by public water systems.

Ensuring that affordable water does not come at the expense of other essential needs is particularly important for households with few resources (**Feature 2**), as they may be forced to reduce spending on water overall ("under-consuming"; Gawel et al., 2013) or reduce spending on other essential needs (Cory & Taylor, 2017). Our review demonstrates that while this is an active area of research, the reviewed measures do not fully capture the compromises households are forced to make by simply removing non-water essential expenditures from incomes. More empirical assessments are needed to understand how paying for water shapes a household's overall spending in higher-income contexts like the US.

We recommend that future studies prioritize assessment of affordability measures by race/ethnicity given the historical inequities faced by communities of color in accessing safe water (Balazs & Ray, 2014; Deitz & Meehan, 2019). This can happen through careful selection of study scale and an emphasis on disaggregating measures to capture potential racial/ethnic disparities (**Feature 3**), as well as other potential social differences relevant to a given context (UNICEF/WHO, 2021).

The relationship between household affordability and environmental sustainability receives far less attention compared with the financial sustainability of water providers. Several recommendations to rectify this gap emerged from our review (**Feature 4**). We recommend that measures focus on essential-needs volume(s) of water in affordability measures, but that studies attend to the limitations of this approach for larger low-income households (Gawel & Bretschneider, 2016, 2017; Howard & Bartram, 2003). Where possible, studies could use a range of essential use volumes and conduct sensitivity analyses to avoid compromising vulnerable groups. Measures that focus on higher volumes of water could be used to represent affordability for households reliant on inefficient and degrading infrastructure and appliances. Finally, studies could simulate how affordability changes in response to "rate shocks" (Fankhauser & Tepic, 2007) to simulate affordability changes in response to environmental changes.

Beyond the four defining features summarized with recommendations from the ongoing debates in Figure 2, there are two additional areas critical to the development of tractable affordability measures—the criteria chosen to represent affordability and the availability of data. There is likely no single criterion for affordability that definitively captures its nuances. Research should identify multiple types of affordability criteria, beyond thresholds, to capture a range of affordability scenarios and relate these to HRTW and SDGs. When using affordability ratios, comparisons across several thresholds may provide benchmarking points without forcing a binary delineation of (un)affordability onto households and communities. Beyond ratios, indicators and evaluation criteria for disconnections should be developed to capture some of the more severe impacts of unaffordable water, especially considering the COVID-19 pandemic and its intimate reliance on safe water access (SWRCB, 2021b). Recent work combined the prevalence of disconnections with affordability analysis across income levels and water system ownership types in California, discovering the critical impact of regulatory and institutional forms on household affordability (Onda & Tewari, 2021). Such efforts demonstrate how affordability assessments can capture defining features of affordability as a HRTW and SDG while complementing a need for policy intervention evaluation (Pierce et al., 2021).

Even with a relevant set of measures and criteria established, comprehensive affordability data remains a barrier for translating research into practice. Policy efforts cannot readily acquire household-level information, complicating efforts to develop nuanced measures that incorporate norms like social equity and sustainability. In these contexts, complementary measures on poverty levels or social-demographic characteristics can improve the interpretability of coarse-scale affordability measures (UNICEF/WHO, 2021). The progressive realization of the HRTW and SDG 6, however, will require improved data collection and sampling to evaluate affordability measures at various scales. Available data on water access has historically been subpar in the US (Beecher et al., 2020; U.S. GAO, 2011), and unified efforts to improve data accessibility and quality are critical (Josset et al., 2019).

Many of the recommendations presented in this review corroborate those recently proposed in a UNICEF/WHO report regarding water affordability measurement in the context of the SDGs (UNICEF/WHO, 2021). Recommendations from the report emphasize the importance of strengthening global datasets, assessing full costs to households (**Feature 1**) to obtain a minimum amount of water (**Features 2** and **4**), stratifying affordability by geography, social-economic categories, or water access levels (**Feature 3**), assessing the impact on the long-term sustainability of utilities (cost-recovery) and water availability (**Feature 4**), and developing consensus around affordability thresholds. The recommendations in our review would therefore bring water affordability measurements in the US in line with recommended affordability measures internationally.

7 | CONCLUSION

In the US, as in other high-income countries with high levels of social and economic inequality, water affordability is a growing social and ethical problem given the essentiality of water to human life and flourishing. Today, a focus on cost burdens to households and individuals has displaced the limited historical focus on water affordability as simply a utility-level cost-recovery problem. New norms are needed to guide the measurement and assessment of affordability under this new paradigm, and we demonstrate how the HRTW and SDGs offer pillars to support this effort. Our review proposes four defining features of water affordability based on the norms espoused by the HRTW and SDGs and identifies several areas for researchers and practitioners to consider when developing water affordability measures. We seek to support researchers and practitioners who develop and use affordability measures with a broader goal to ensure progress on the HRTW and SDGs. Ultimately, theoretical aspirations must be balanced with the tractability of affordability measurement in practice. Guiding norms can offer insight into why one choice may better represent the problem at hand over another, when decisions are limited by lack of clear-cut criteria to evaluate affordability.

There is not one way to measure water affordability, just as there is not one way that people access water or bear the burden of its costs. The norms that analysts and policymakers use to decide what to measure will ultimately influence which problems become "visible", and thereby which interventions are seen as viable to addressing water access issues. Transparency in the choices that analysts make—including the use of these international norms for water access—will improve comparability across studies and our understanding of affordability overall.

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CONFLICT OF INTEREST

The authors have no known conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Jessica J. Goddard: Conceptualization (equal); data curation (lead); investigation (lead); project administration (lead); writing – original draft (lead). **Isha Ray:** Conceptualization (equal); investigation (equal); methodology (equal); project administration (supporting); writing – original draft (equal). **Carolina Balazs:** Conceptualization (equal); investigation (equal); methodology (equal); project administration (supporting); writing – original draft (equal).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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