



**A Global Agenda for Household Water Security:
Measurement, Monitoring, and Management**

Journal:	<i>Journal of the American Water Resources Association</i>
Manuscript ID	JAWRA-20-0107-C.R1
Manuscript Type:	Water Commentary
Date Submitted by the Author:	n/a
Complete List of Authors:	Wutich, Amber Jepson, Wendy; Texas A&M University System Stoler, Justin; University of Miami Thomson, Patrick; Oxford University Kooy, Michelle; University of Amsterdam Brewis, Alexandra; Arizona State University Staddon, Chad Meehan, Katie; King's College London
Category Headings:	GEOGRAPHY, WATER RESOURCES MANAGEMENT
Key Terms:	water security, measurement, interventions, monitoring and evaluation, governance

A Global Agenda for Household Water Security:
Measurement, Monitoring, and Management

Authors: Amber Wutich, Wendy E. Jepson, Justin Stoler, Patrick Thomson, Michelle Kooy,
Alexandra Brewis, Chad Staddon, Katie Meehan

School of Human Evolution and Social Change (Wutich), Arizona State University, Arizona,
USA; Department of Geography (Jepson), Texas A&M University, Texas, USA; Department of
Geography and Regional Studies (Stoler), University of Miami, Florida, USA; School of
Geography and the Environment (Thomson), Oxford University, Oxford, UK; Department of
Human Geography, Planning and International Development Studies (Kooy), IHE-Delft Institute
for Water Education, Delft & University of Amsterdam, Noord-Holland, The Netherlands;
School of Human Evolution and Social Change (Brewis), Arizona State University, Arizona, US;
Department of Geography and Environmental Management (Staddon), University of the West of
England, Bristol, UK; Department of Geography (Meehan), King’s College London, London,
UK (Correspondence to: awutich@asu.edu)

Research Impact Statement

We present an agenda for Household Water Insecurity research that addresses measurement, monitoring, and management with the goal of enhancing long-term sustainability and water security for all.

ABSTRACT

Water scholarship has advanced considerably in recent decades. Despite this remarkable progress, water challenges may be growing more quickly than our capacity to solve them. While much progress has been made toward achieving Sustainable Development Goal 6—water and sanitation for all—new stressors have emerged to threaten this progress. Far from being a problem of the Global South, recent research shows that water insecurity is very much a global phenomenon—and one that has been, until recently, seriously neglected in the Global North. This indicates a strong need for innovative measurement of who experiences water insecurity, new approaches for monitoring the efficacy of water interventions, and more effective management of complex, mobile, and multiple water infrastructures to achieve water security. In this paper, we introduce the Household Water Insecurity (HWISE) approach to addressing these concerns. First, we suggest ways to improve the measurement of water insecurity—pinpointing problems at the household and individual levels—in ways that can inform policymaking with improved precision. Second, we discuss ways that new information and communication technology (ICT) can improve monitoring and indicate where water infrastructure repairs and investments are most needed. Third, we highlight the need for new approaches to managing complex water infrastructures in more inclusive and democratic ways.

(Key words: water security; measurement; interventions; monitoring and evaluation; governance.)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1. INTRODUCTION

Water scholarship has advanced considerably in recent decades. Engineers have identified ground-breaking technologies to track, treat, and test water. Geoscientists have refined our understanding of how surface and underground waters interact ecologically to change the quality and quantity of water in one place, often affecting users and uses elsewhere. Economists and policy makers have developed new mechanisms to improve water conservation and management. Water scholars now understand that integrated multidisciplinary approaches to hydro-social dynamics—focused equally on hydrology, engineering, economy, and society—are essential to achieving Sustainable Development Goal 6 and to managing water sustainably and equitably (O'Donnell and Garrick 2019; Larson 2020). Such achievements demonstrate how far we have come together. Yet, despite this remarkable progress, water challenges may be growing more quickly than our collective capacity to solve them.

While we have made great strides toward achieving Sustainable Development Goal 6—water and sanitation for all—new stressors have emerged to threaten this progress. Global climate change is changing the spatiotemporal distribution of water resources, driving migration in ways that may leave old infrastructure abandoned and new infrastructure desperately needed. Wildfires, hurricanes, floods, and other environmental hazards can threaten existing water infrastructures. Wildfires in California, U.S., for example, forced migration due to lost housing, melted buried pipes, and contaminated local water infrastructure with benzene and other volatile organic compounds (Bladon et al 2014; Proctor et al 2020). Droughts, groundwater depletion, and general physical water scarcity may force people to depend on multiple mobile water sources rather than

monolithic fixed grid-based water infrastructures (Pauloo et al 2020). Unmet, long-standing infrastructure investment and maintenance backlogs mean that some communities may never receive adequate water provision, while existing water infrastructures become less resilient (Juuti et al. 2019, Erban and Walker 2019).

This is not just a problem in the Global South. Recent research shows that water insecurity is very much a global phenomenon—and one that has been seriously neglected in the Global North (Meehan et al. 2020a, 2020b). This indicates a strong need for more precise tracking of who (and where) water insecurity is experienced across development gradients; new approaches for monitoring the efficacy of water interventions; and more effective management of complex, mobile, and multiple water infrastructures to achieve water security (Pooi and Ng 2018; Zhou et al 2020; Patil et al 2020; Yang et al 2020).

In this paper, we introduce the Household Water Insecurity (HWISE) approach to addressing measurement, monitoring, and management. Water security implies meeting human and environmental needs for water (Bakker 2012). In our approach, we focus on individual and household needs for safe, adequate, and affordable water to support a healthy and thriving life (Jepson et al. 2017a, b). Our approach has three main goals. First, we suggest ways to improve the measurement of water insecurity—pinpointing problems at the household and individual levels—in ways that can inform policymaking with greater precision. Second, we discuss ways that new information and communication technology (ICT) can improve monitoring and indicate where water infrastructure repairs and investments are most needed. Third, we highlight the need for new approaches to managing complex water infrastructures in more inclusive and democratic ways.

2. GOAL 1: MEASURING WATER INSECURITY

One primary challenge to advancing the study of household water insecurity has been developing valid, reliable, meaningful measures of household water security status. Without knowing who is experiencing water insecurity, it is difficult to pinpoint where changes are needed. To date, there is no consensus method for determining if households and individuals are water-insecure, and several competing approaches are vying for attention (Octavianti and Staddon, forthcoming). Here, we suggest several promising new approaches to measuring water insecurity.

Social scientists deploy a range of methodologies to measure multidimensional phenomena like water insecurity. One approach typically constructs a numerical scale from the aggregated results of a household survey comprised of items developed through rigorous validation processes (Boateng et al, 2018). Since the development of the first household water insecurity scale (Wutich and Ragsdale 2008, Hadley and Wutich 2009), many researchers have developed and validated water insecurity scales to fit a range of global conditions, languages, and concerns (e.g., Jepson, Wutich, et al. 2017b, Tsai et al. 2015).

Building on the recent global push to develop water insecurity scales, the HWISE Scale is a cross-culturally-validated scale for assessing household water insecurity in low- and middle-income countries (Young, Boateng, et al. 2019, Young, Collins, et al. 2019). Developed using data from sites in 23 countries, the scale measures water adequacy, reliability, and accessibility in valid and reliable ways across low and middle-income sites using 12 survey items. Each item asks

respondents, who have been identified as responsible for household water management, to report how often they experienced any of 12 different water insecurity-related problems over the preceding four weeks. Subsequent projects developed a shorter four-item scale (Young et al. 2020) and a two-item screener (Wutich et al. 2020a).

Octavianti and Staddon (forthcoming) suggest that water insecurity scales tend to be either “resource-based” or “experience-based,” with the former tending to resemble the sorts of discrete modelling exercises that obfuscate social, cultural and other sorts of variability. A compromise approach could be to use separate indices to measure the sub-dimensions of water insecurity (Tomaz et al. 2020). These indices quantify how different domains of water insecurity experiences influence overall water insecurity experiences, and how each domain pushes households across severity thresholds. A remaining challenge is to translate the insights from scale and index development in the Global South for use in the Global North.

To unpack water insecurity *within* households, new methods are being developed to track the uneven distribution of water insecurity based on age, gender, and other factors (Wutich et al. 2017). The water diary, for example, is a classic method for tracking household and individual water use (White, Bradley and White 1972) that has recently been updated and improved (Wutich 2009, Hoque and Hope 2018, Hoque and Hope 2019). It is an important source of data on water use per person per day where water meter data are not available, as in situations where households rely on multiple water sources or are not connected to a central water grid. When compared against water consumption benchmarks, water diaries can identify water-insecure households and individuals with high precision.

Leveraging these methods, recent research has established the varied adverse effects of household water insecurity on individual health, beyond the long-recognized impacts of sanitation-related disease (Rosinger and Young 2020). These impacts include undernutrition (Schuster et al. 2020), mental illness (Wutich, Brewis, and Tsai 2020), elevated risk of hypertension (Brewis, Choudhary, and Wutich 2019), falls and other physical trauma (Geere et al. 2018, Geere and Cortobius 2017), diarrhea (Jepson et al. in review), and intimate partner violence (Choudhary 2020).

Together, the growing family of HWISE methods help us address some of the most trenchant critiques of the Sustainable Development Goals and the Millennium Development Goals that preceded them: specifically, that they traffic in “nonsense statistics” unable to tell us who lacks safe, sufficient water (Satterthwaite 2003, Nganyanyuka et al. 2014, Onda et al. 2012). These new methods enable us to identify which households and individuals suffer water insecurity. By pairing these methods with geospatial data infrastructure and analytics, we can turn these precise, systematically-collected data into a more comprehensive understanding of larger-scale patterns of water insecurity.

3. GOAL 2: MONITORING WATER INSECURITY

Recent methodological developments in measuring household water insecurity present a compelling opportunity for the integration of information and communication technology (ICT) using geospatial and mobile health (mHealth) platforms. Geospatial approaches, such as those using geographic information systems (GIS), remote sensing (RS) and Global Navigation Satellite

1
2
3 Systems (GNSS), have long been used for mapping and modeling residential water demand at the
4 household level around the world. They have facilitated research on water quality in Brazil
5 (Zeilhofer et al. 2007), improved decision-support for residential water use in Texas (Xie 2009)
6 and Australia (Jayarathna et al. 2017), characterized water fetching burdens in Uganda (Pearson
7 2016), and addressed differences in willingness-to-pay for water in New Zealand (Tait, Baskaran
8 et al. 2012).

19 These forms of ICT, enabled by the global ubiquity of mobile phones and GNSS, can address
20 information gaps in the WASH sector by transforming how data are generated, communicated,
21 and shared (Hutchings et al. 2012). Most applications aim to collect and analyze water data from
22 remote regions in order to improve infrastructure allocation and long-term project monitoring,
23 evaluation, and iterative planning. Popular mobile applications such as Akvo FLOW have been
24 used to monitor WASH services in Nepal and India (Lama and Khatri 2014, Umar, Thatte, and
25 Varma 2017), and throughout Africa (Mumbo and Nyambala 2013). Human health has only
26 recently been integrated into mHealth WASH applications, with limited attention to socio-cultural
27 factors. Citizen science mobile applications such as miniSASS have proved useful for collecting
28 data about local surface water quality and educating local populations about the importance of
29 protecting water sources (Vallabh et al, 2016). The scientific community is learning from the
30 mixed results of early mHealth applications (Aranda-Jan, Mohutsiwa-Dibe, and Loukanova 2014,
31 Mechael et al. 2010), with new mobile WASH messaging applications showing promising results
32 (Bhuyian et al. 2020). Mobile technology presents an opportunity, as discussed in Box 1, for cross-
33 sectional water insecurity household surveys to be replaced by prospective and real-time water
34 insecurity monitoring tools for scaling from communities to regions.

INSERT BOX 1.

As ICT plays an increasing role in efforts to address water insecurity, some technologies will enhance existing ways of working and thinking, while others allow us to rethink the way we address water insecurity. Mobile data and the Internet of Things (IoT) enable remote information gathering, with data now often generated with the speed and low cost to support operations and planning, not just monitoring and evaluation (Thomson et al. 2012a, 2012b). For example, the use of sensors in Kenya and Ethiopia reduced delays in handpump maintenance (University of Oxford 2014, Nagel et al. 2015), and monitoring larger boreholes contributed to drought preparedness (Thomas et al. 2020, Turman-Bryant et al. 2019). Such ICT platforms can also democratize water data by breaking the experts’ long-standing monopoly over data and even demystifying the processes of indicator construction and data collection, as was the case with the South African miniSASS project (Vallabh et al, 2016).

While these technologies may prove to be transformative, IoT and AI do not in themselves reduce household water insecurity: a packet of data or a predictive model will not fix a pump, enforce compliance with environmental standard, negotiate equitable tariffs or relieve women and children of water work. These are tools to support robust, equitable management and governance, not replace them. Current research on these technologies focuses primarily on the operational advantages they offer. There is little examination of unintended consequences and potential negative impacts, an exception being the literature on pre-paid water meters (Dugard 2008, Von Scnitzler 2008, Heymans, Eales, and Franceys 2014). Technology and data are neither exclusively

1
2
3 a force for good, nor do they always necessarily result in what users intended. Data-driven gains
4
5 in efficiency will only reduce the most egregious forms of water insecurity when integrated into
6
7 social approaches to managing water, and if they are viewed as a complementary to more
8
9 traditional technologies, not substitutes for them. We discuss an example in Box 2.
10
11
12
13

14
15 INSERT BOX 2.
16
17
18

19 20 **3. GOAL 3: MANAGING WATER SECURITY PROGRESS** 21 22

23
24 The integration of ICT approaches using regional-scale GIS and remote sensing data—in
25
26 conjunction with individual and household-scale data—can accelerate our understanding of how
27
28 demographic and environmental policies affect water security. We can learn, for example, how
29
30 migration policy or natural resource use shapes water insecurity. In doing so, this technology can
31
32 help us identify, and in some cases redesign, local governance approaches and WASH
33
34 interventions for achieving global water security.
35
36
37
38
39

40 The use of information technology in the water sector must be accompanied by institutional
41
42 reform, underpinned by rigorous research from diverse viewpoints to ensure any new technology
43
44 does not reinforce existing inequalities. Data and ICT can just as easily be used to exclude as to
45
46 provide, as the example of pre-paid meters in South Africa demonstrates (Bond 2019). New
47
48 technologies can generate large volumes of time-stamped and geo-referenced quantitative data;
49
50 their alluring potential can obscure its limitations and privacy implications. Considering who has
51
52 access, to what ends, and how these data support the larger goal of household water security are
53
54
55
56
57
58
59
60

vital to the success of these projects. For example, efficacy of Smart Handpumps hinges on building new partnerships between state agencies, service providers, local water institutions, and householders (Thomson and Koehler, 2016). Improved data on household water insecurity must therefore be accompanied by efforts to transform decision-making about water management and provision.

Figure 1 shows how the three key goals—measurement, monitoring, and management—can be integrated. Measurement is essential to identify where water insecurity exists. Monitoring is needed to identify complex dynamics and track the need for interventions. Management ensures that institutions, policies, communities and relationships monitor decision-making that supports justice and equity in water security.

INSERT FIGURE 1

Despite many promising developments, we urge caution in assuming that new data or reworked local technologies will blaze a pathway to achieving SDG 6. Addressing water insecurity will require more significant changes to how we address water management challenges. The next necessary step is experimentation with new modes of water citizenship built on the understanding that multiple infrastructures are the norm, not the exception, in water-insecure households (Bond 2019, Deedat and Cottle 2002, Molden, Khanal, and Pradhan 2020). The use of multiple infrastructures can represent a mode of development emerging in parallel or at odds with formal networked infrastructure (Furlong and Kooy 2017). It can also reflect a deliberate strategy of differentiation to preserve an institutional or financial public capacity to deliver subsidized

1
2
3 services, especially to the poor (Furlong 2014). Managing a broader array of entitlements to water
4 and infrastructure (Anand 2017, Rodina and Harris 2016) can begin a shift toward new, more
5
6 inclusive modes of water citizenship.
7
8
9

10
11
12 Fostering inclusive and engaged water citizenship requires existing institutions to open space for
13 new voices and concerns that may challenge conventional, top-down engineering assumptions.
14
15 Our future work demands that we find new and effective ways to address these governance
16 challenges. A critical lesson from early HWISE efforts is the need to elevate lay knowledge,
17 experts, and expertise from the Global South—including theories, solutions, and best practices—
18
19 into its central place in global water leadership (Muchie et al. 2017, Allen et al. 2017, Sultana
20 2018, Pacheco-Vega 2019). At the same time, we need to put expertise from the Global North in
21
22 its place, recognizing its usefulness for generating regional knowledge and solutions, but not
23
24 necessarily as a blueprint for a world facing increasingly complex water challenges (Furlong and
25
26 Kooy 2017).
27
28
29
30
31
32
33
34
35
36
37

38 5. CONCLUSION

39
40
41
42 In this paper, we have presented an agenda for advancing research and intervention to address
43 water insecurity, which we call the Household Water Insecurity (HWISE) approach. Our agenda
44 emerges from a decade of empirical investigation, theoretical reflection, and multidisciplinary
45
46 collaboration on water security (Jepson et al. 2017a) in the Global North and Global South. The
47
48 core of our proposed research agenda is to advance toward to goal of ensuring that *every* individual
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

and household can secure water to thrive in the context of diverse and often inadequate systems without compromising sustainable water management.

Our first goal has aimed to advance the science of how we know who is water insecure. The HWISE research community has developed new methods for tracking water insecurity, across time and space, for individuals and households. Following this, we argued, new integrated ICT approaches can help us monitor complex trends and identify places where water interventions are most needed. While measurement and monitoring have transformative potential, we stress that these tools must be used to support and enhance just water governance. Our third goal is to promote water governance that fosters inclusive and engaged water citizenship, and that better integrates under-appreciated, complex, mobile, and multiple infrastructures that can contribute to global water security.

Taken together, new progress in measurement, monitoring, and management can bring about socio-technical and socio-political transformations that enable sustainable water resource management. While new technologies and infrastructures are not a panacea, they can ensure that efforts are targeted where they can help most. At the same time, approaches to managing water—centering knowledge from the Global South, re-examining old solutions that depend on multiple infrastructures, planning for a higher-mobility future—can bring us much closer to achieving water security for all.

For Peer Review

LITERATURE CITED

Allen, A., Hofmann, P., Mukherjee, J., & Walnycki, A. (2017). Water trajectories through non-networked infrastructure: insights from peri-urban Dar es Salaam, Cochabamba and Kolkata. *Urban Research & Practice*, 10(1), 22-42.

Anand, Nikhil. 2017. *Hydraulic city: Water and the infrastructures of citizenship in Mumbai*: Duke University Press.

Aranda-Jan, Clara B., Neo Mohutsiwa-Dibe, and Svetla Loukanova. 2014. "Systematic review on what works, what does not work and why of implementation of mobile health (mHealth) projects in Africa." *BMC Public Health* 14 (1):188. doi: 10.1186/1471-2458-14-188.

Bakker, K. (2012). Water security: research challenges and opportunities. *Science*, 337(6097), 914-915.

Bhuyian, Md Sazzadul Islam, Ronald Saxton, Khaled Hasan, Jahed Masud, Fatema Zohura, Shirajum Monira, Shwapon Kumar Biswas, M. Tasdik Hasan, Tahmina Parvin, Ismat Minhaj, Kazi Md Zillur Rahman, Nowshin Papri, Mahamud-ur Rashid, Lubaba Sharin, Alana Teman, Elizabeth D. Thomas, Kelsey Alland, Alain Labrique, David A. Sack, Jamie Perin, Munirul Alam, and Christine Marie George. 2020. "Process evaluation for the delivery of a water, sanitation, and hygiene mobile health program: Findings from the randomized controlled trial of the CHoBI7 Mobile Health Program." *Tropical Medicine & International Health* in press. doi: 10.1111/tmi.13414.

Bladon, K. D., Emelko, M. B., Silins, U. & Stone, M. 2014. Wildfire and the future of water supply. *Environ. Sci. Technol.* 48 8936–8943.

- Boateng, Godfred, T. B. Neilands, E. A. Frongillo, H. R. Melgar-Quinonez, and S. L. Young, 2018
“Best practices for developing and validating scales for health, social, and behavioral
research: a primer,” *Front. Public Heal.*, vol. 6, no. June, pp. 1–18.
- Bond, Patrick. 2019 “Class, race, space and the ‘right to sanitation’”. *Water Politics: Governance,
Justice and the Right to Water*, Routledge, p.189.
- Brewis, Alexandra, Neetu Choudhary, and Amber Wutich. 2019. "Low water access as a gendered
physiological stressor: Blood pressure evidence from Nepal." *American Journal of Human
Biology* 31 (3):e23234.
- Choudhary, Neetu. 2020. "Sub-optimal household water access is associated with greater risk of
intimate partner violence against women: evidence from Nepal." *Journal of Water and
Health*.
- Deedat, H., and E. Cottle. 2002. "Cost recovery and prepaid water meters and the cholera outbreak
in KwaZulu-Natal: a case study in Madlebe." In *Cost recovery and the crisis of service
delivery in South Africa*, 81-97.
- Dugard, Jackie. 2008. "Rights, Regulation and Resistance: The Phiri water campaign." *South
African Journal on Human Rights* 24 (3):593-611. doi: 10.1080/19962126.2008.11864972.
- Erban, L. & Walker, H. A. 2019. Beyond Old Pipes and Ailing Budgets: Systems Thinking on 21st
Century Water Infrastructure in Chicago. *Frontiers in Built Environment* 5, 124.
- Façanha, Islene. 2019. "Water and Women’s Participation The Case of One Million Rural Cisterns
Program in Serra Talhada, Pernambuco." *wH2O: The Journal of Gender and Water* 6 (1).
- Furlong, Kathryn. 2014. "STS beyond the “modern infrastructure ideal”: Extending theory by
engaging with infrastructure challenges in the South." *Technology in Society* 38:139-147.
doi: 10.1016/j.techsoc.2014.04.001.

Furlong, Kathryn, and Michelle Kooy. 2017. "Worlding Water Supply: Thinking Beyond the Network in Jakarta." *International Journal of Urban and Regional Research* 41 (6):888-903. doi: 10.1111/1468-2427.12582.

Geere, Jo-Anne, and Moa Cortobius. 2017. "Who carries the weight of water? Fetching water in rural and urban areas and the implications for water security." *Water Alternatives* 10 (2):513-540.

Geere, Jo-Anne Lee, Moa Cortobius, Jonathan Harold Geere, Charlotte Christiane Hammer, and Paul R Hunter. 2018. "Is water carriage associated with the water carrier's health? A systematic review of quantitative and qualitative evidence." *BMJ global health* 3 (3).

Greeff, Heloise, Achut Manandhar, Patrick Thomson, Robert Hope, and David A. Clifton. 2019. "Distributed Inference Condition Monitoring System for Rural Infrastructure in the Developing World." *IEEE Sensors Journal* 19(5):1820–28.

Hadley, Craig, and Amber Wutich. 2009. "Experience-based measures of food and water security: biocultural approaches to grounded measures of insecurity." *Human Organization* 68 (4):451-460.

Heymans, Christiaan, Kathy Eales, and Richard Franceys. 2014. *The Limits and Possibilities of Prepaid Water in Urban Africa*: World Bank.

Hoque, S. F., and R. Hope. 2019. "Examining the economics of affordability through water diaries in coastal Bangladesh." *Water Economics and Policy*.

Hoque, Sonia Ferdous, and Robert Hope. 2018. "The water diary method – proof-of-concept and policy implications for monitoring water use behaviour in rural Kenya." *Water Policy* 20 (4):725-743. doi: 10.2166/wp.2018.179.

- Hutchings, Misha T., Anurupa Dev, Meena Palaniappan, Veena Srinivasan, Nithya Ramanathan, and John Taylor. 2012. *mWASH: Mobile phone applications for the water, sanitation, and hygiene sector*. Edited by Nancy Ross and Paula Luu. Oakland, CA: Pacific Institute.
- Jayarathna, Lasinidu, Darshana Rajapaksa, Shunsuke Managi, Wasantha Athukorala, Benno Torgler, Maria A. Garcia-Valiñas, Robert Gifford, and Clevo Wilson. 2017. "A GIS based spatial decision support system for analysing residential water demand: A case study in Australia." *Sustainable Cities and Society* 32:67-77. doi: 10.1016/j.scs.2017.03.012.
- Jepson, Wendy, Jessica Budds, Laura Eichelberger, Leila Harris, Emma Norman, Kathleen O'Reilly, Amber Pearson, Sameer Shah, Jamie Shinn, and Chad Staddon. 2017a. "Advancing human capabilities for water security: A relational approach." *Water Security* 1.
- Jepson, Wendy E., Amber Wutich, Shalean M. Collins, Godfred O. Boateng, and Sera L. Young. 2017b. "Progress in household water insecurity metrics: a cross-disciplinary approach." *WIREs Water* 4 (3):e1214. doi: 10.1002/wat2.1214.
- Jepson, Wendy, Justin Stoler, Juha Baek, Javier Moran, Felipe Uribe, and Genny Carrillo. (under review) "Measuring household water insecurity experience as a proxy for health outcomes in urban Mexico" *BMJ Open*
- Juuti, P, Maatila, H, Rajaala, R., Schwartz, K., Staddon, C., 2019 *Resilient Water Systems and Services: the foundation of well-being*, IWA Publishing.
- Kugler, Tracy A., Kathryn Grace, David J. Wrathall, Alex de Sherbinin, David Van Riper, Christoph Aubrecht, Douglas Comer, Susana B. Adamo, Guido Cervone, Ryan Engstrom, Carolynne Hultquist, Andrea E. Gaughan, Catherine Linard, Emilio Moran, Forrest Stevens, Andrew J. Tatem, Beth Tellman, and Jamon Van Den Hoek. 2019. "People and

1
2
3 Pixels 20 years later: the current data landscape and research trends blending population
4 and environmental data." *Population and Environment*. doi: 10.1007/s11111-019-00326-
5
6
7
8 5.
9

10 Lama, Jigmy P., and Giri R. Khatri. 2014. "Akvo FLOW in Nepal: real time monitoring of WASH
11 services." 37th WEDC International Conference, 2014.
12
13

14 Larson, Rhett. 2020. *Just Add Water: Solving the World's Problems Using its Most Precious*
15 *Resource*. Oxford, New York: Oxford University Press.
16
17

18 Mapulanga, Annie Mwayi, and Hisahiro Naito. 2019. "Effect of deforestation on access to clean
19 drinking water." *Proceedings of the National Academy of Sciences* 116 (17):8249-8254.
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

26 Mechael, P., H. Batavia, N. Kaonga, S. Searle, A. Kwan, A. Goldberger, L. Fu, and Ossman J.
27
28 2010. *Barriers and gaps affecting mHealth in low and middle income countries: Policy*
29 *white paper, Center for Global Health and Economic Development, Earth Institute*. New
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

35 Meehan, Katie, Wendy Jepson, Leila Harris, Amber Wutich, Melissa Beresford, Amanda Fencel, Jonathan
36
37 London, Lucero Radonic, Gregory Simon, Christian Wells, Nicole Wilson, Ellis Adjei Adams,
38
39 Alexandra Brewis, Victoria Harrington[†], Yanna Lambrinidou, Deborah McGregor, Robert Patrick,
40
41 Benjamin Pauli, Amber L. Pearson, Sameer Shah[†], Dacotah Splichalova[†], Cassandra Workman,
42
43 and Sera Young. (2020) Exposing the myths of household water insecurity in the global North: a
44
45 critical review. *Wiley Interdisciplinary Reviews (WIREs): Water* 7(6): e1486. doi:
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

50 Meehan, Katie, Jason R. Jurjevich, Nicholas M.J.W. Chun, and Justin Sherrill. (2020) Geographies of
51
52
53
54
55
56
57
58
59
60

- 1
2
3 *Academy of Science (PNAS) of the United States of America.* 117(46): 28700-28707.
4
5 <https://doi.org/10.1073/pnas.2007361117>
6
7 Molden, Olivia C., Anoj Khanal, and Nita Pradhan. 2020. "The pain of water: a household
8 perspective of water insecurity and inequity in the Kathmandu Valley." *Water Policy* 22
9
10 (S1):130-145. doi: 10.2166/wp.2018.116.
11
12
13 Muchie, M., Bhaduri, S., Baskaran, A., & Sheikh, F. A. (Eds.). 2017. *Informal sector innovations:
14 Insights from the global South.* Routledge.
15
16 Mukherjee, Subham, Wiebke Bebermeier, and Brigitta Schütt. 2018. "An overview of the impacts
17 of land use land cover changes (1980–2014) on urban water security of Kolkata." *Land* 7
18
19 (3):91. doi: 10.3390/land7030091.
20
21
22 Mumbo, Gordon, and Marceline Nyambala. 2013. "Everyone forever: water for people's model
23 for ending Africa's water challenges." 36th WEDC International Conference, 2013.
24
25 Nagel, Corey, Jack Beach, Chantal Iribagiza, and Evan A. Thomas. 2015. "Evaluating Cellular
26 Instrumentation on Rural Handpumps to Improve Service Delivery—A Longitudinal Study
27 in Rural Rwanda." *Environmental Science & Technology* 49 (24):14292-14300. doi:
28 10.1021/acs.est.5b04077.
29
30 Nganyanyuka, K., J. Martinez, A. Wesselink, J. H. Lungu and Y. Georgiadou, 2014. Accessing
31 water services in Dar es Salaam: Are we counting what counts? *Habitat International*
32 44:358-366.
33
34 O'Donnell, Erin L., and Dustin E. Garrick. 2019. "The diversity of water markets: Prospects and
35 perils for the SDG agenda." *WIREs Water* 6 (5):e1368. doi: 10.1002/wat2.1368.
36
37
38 Octavianti T and C. Staddon, Forthcoming, "A review of 86 assessment tools measuring water
39 security," *WIREs Water*.
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Onda, K., J. LoBuglio and J. Bartram, 2012. Global access to safe water: Accounting for water quality and the resulting impact on MDG progress. *International Journal of Environmental Research and Public Health* 9:880-894.

Pacheco-Vega, R. 2019. (Re) theorizing the politics of bottled water: Water insecurity in the context of weak regulatory regimes. *Water*, 11(4), 658.

Patil, R., Ahmad, D., Balkundae, P., Kausley, S. & Malhotra, C. 2020. Development of low cost point-of-use (POU) interventions for instant decontamination of drinking water in developing countries. *Journal of Water Process Engineering* 37, 101435.

Pauloo, R. et al. 2020. Domestic well vulnerability to drought duration and unsustainable groundwater management in California’s Central Valley. *Environmental Research Letters* 15, 044010.

Pearson, A. L., 2016. Comparison of methods to estimate water access: a pilot study of a GPS-based approach in low resource settings. *International Journal of Health Geographics* 15:33.

Pooi, C. K. & Ng, H. Y. 2018. Review of low-cost point-of-use water treatment systems for developing communities. *NPJ Clean Water* 1, 1-8.

Proctor, C. R., Lee, J., Yu, D., Shah, A. D. & Whelton, A. J. 2020. Wildfire caused widespread drinking water distribution network contamination. *AWWA Water Science* 2, e1183.

Rodina, Lucy, and Leila M Harris. 2016. "Water Services, Lived Citizenship, and Notions of the State in Marginalised Urban Spaces: The case of Khayelitsha, South Africa." *Water Alternatives* 9 (2).

- Rosinger, Asher Y, and Sera L Young. 2020. "The toll of household water insecurity on health and human biology: Current understandings and future directions." *Wiley Interdisciplinary Reviews: Water*:e1468.
- Satterthwaite D. The Millennium Development Goals and urban poverty reduction: great expectations and nonsense statistics. *Environment and Urbanization*. 2003;15(2):179–190.
- Schuster, Roseanne C., Margaret S. Butler, Amber Wutich, Joshua D. Miller, Sera L. Young, and Household Water Insecurity Experiences-Research Coordination Network. 2020. "“If there is no water, we cannot feed our children”: The far-reaching consequences of water insecurity on infant feeding practices and infant health across 16 low- and middle-income countries." *American Journal of Human Biology* 32 (1):e23357. doi: 10.1002/ajhb.23357.
- Sultana, F. 2018. Water justice: why it matters and how to achieve it. *Water International*, 43(4), 483-493.
- Tait, P., Baskaran, R., Cullen, R., & Bicknell, K. 2012. Nonmarket valuation of water quality: Addressing spatially heterogeneous preferences using GIS and a random parameter logit model. *Ecological Economics*, 75, 15-21.
- Tellman, Beth, Robert I. McDonald, Joshua H. Goldstein, Adrian L. Vogl, Martina Flörke, Daniel Shemie, Russ Dudley, Rachel Dryden, Paulo Petry, Nathan Karres, Kari Vigerstol, Bernhard Lehner, and Fernando Veiga. 2018. "Opportunities for natural infrastructure to improve urban water security in Latin America." *PLOS ONE* 13 (12):e0209470. doi: 10.1371/journal.pone.0209470.
- Thomas, Evan, Elizabeth Jordan, Karl Linden, Beshah Mogesse, Tamene Hailu, Hussein Jirma, Patrick Thomson, Johanna Koehler, and Greg Collins. 2020. "Reducing drought

- emergencies in the Horn of Africa." *Science of the Total Environment* 727:138772-138772. doi: 10.1016/j.scitotenv.2020.138772.
- Thomson, Patrick, Rob Hope, and Tim Foster. 2012a. "GSM-enabled remote monitoring of rural handpumps: a proof-of-concept study." *Journal of Hydroinformatics* 14 (4):829-829. doi: 10.2166/hydro.2012.183.
- Thomson, Patrick, Rob Hope, and Tim Foster. 2012b. "Is Silence Golden? Of Mobiles, Monitoring, and Rural Water Supplies." *Waterlines* 31(4):280–92.
- Thomson, Patrick and Johanna Koehler. 2016. "Performance-Oriented Monitoring for the Water SDG – Challenges, Tensions and Opportunities." *Aquatic Procedia* 6:87–95.
- Tomaz, Paula, Wendy Jepson, and Jader de Oliveira Santos. 2020. "Urban Household Water Insecurity from the Margins: Perspectives from Northeast Brazil." *The Professional Geographer* 0 (0):1-18. doi: 10.1080/00330124.2020.1750439.
- Tsai, A. C., B. Kakuhikire, R. Mushavi, D. Vořechovská, J. M. Perkins, A. Q. McDonough and D. R. Bangsberg. 2015. "Population-based study of intra-household gender differences in water insecurity: reliability and validity of a survey instrument for use in rural Uganda." *Journal of Water and Health* 14:280-292.
- Turman-Bryant, Nick, Corey Nagel, Lauren Stover, Christian Muragijimana, Evan A. Thomas. 2019. "Improved Drought Resilience Through Continuous Water Service Monitoring and Specialized Institutions—A Longitudinal Analysis of Water Service Delivery Across Motorized Boreholes in Northern Kenya." *Sustainability* 11 (11):3046-3046. doi: 10.3390/su11113046.

- Umar, Asad, Prasann Thatte, and Satviki Varma. 2017. "Mobile-based tracking system to ensure sustainability of a sanitation programme: experiences from four Indian states." 40th WEDC International Conference, 2017.
- University of Oxford. 2014. *From Rights to Results in Rural Water Services -Evidence from Kyuso, Kenya Smith School Water Programme.*
- Vallabh, P., Lotz-Sisitka, H., O'Donoghue, R. and Schudel, I. 2016, Mapping epistemic cultures and learning potential of participants in citizen science projects. *Conservation Biology*, 30: 540-549. <https://doi.org/10.1111/cobi.12701>
- White, G, David J Bradley, and Anne U. White. 1972. *Drawers of Water: Domestic Water Use in East Africa*. Chicago: University of Chicago Press.
- Wutich, A., and K. Ragsdale. 2008. "Water insecurity and emotional distress." *Social Science & Medicine* 67 (12):2116-2125.
- Wutich, Amber. 2009. "Estimating Household Water Use: A Comparison of Diary, Prompted Recall, and Free Recall Methods." *Field Methods* 21(1):49–68.
- Wutich, A., Budds, J., Eichelberger, L., Geere, J., Harris, L.M., Horney, J.A., Jepson, W., Norman, E., O'Reilly, K., Pearson, A.L. and Shah, S.H. 2017. "Advancing methods for research on household water insecurity." *Water Security*, 2, pp.1-10.
- Wutich, A. 2020. "Water insecurity." *American Journal of Human Biology*, 32(1), e23345.
- Wutich, A., Rosinger, A. Y., Stoler, J., Jepson, W., & Brewis, A. 2020a. "Measuring human water needs." *American Journal of Human Biology*, 32(1), e23350.
- Wutich, Amber, Alexandra Brewis, and Alexander Tsai. 2020b. "Water and mental health." *WIREs Water*:e1461. doi: 10.1002/wat2.1461.

Xie, Hongjie. 2009. "Using remote sensing and GIS technology for an improved decision support: a case study of residential water use in El Paso, Texas." *Civil Engineering and Environmental Systems* 26 (1):53-63. doi: 10.1080/10286600802003666.

Yang, H., Xu, S., Chitwood, D. E. & Wang, Y. 2020. Ceramic water filter for point-of-use water treatment in developing countries: Principles, challenges and opportunities. *Frontiers of Environmental Science & Engineering* 14, 1-10.

Young, Sera L, Godfred O Boateng, Zeina Jamaluddine, Joshua D Miller, Edward A Frongillo, Torsten B Neilands, Shalean M Collins, Amber Wutich, Wendy E Jepson, and Justin Stoler. 2019. "The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries." *BMJ global health* 4 (5):e001750.

Young, Sera L, Shalean M Collins, Godfred O Boateng, Torsten B Neilands, Zeina Jamaluddine, Joshua D Miller, Alexandra A Brewis, Edward A Frongillo, Wendy E Jepson, and Hugo Melgar-Quinonez. 2019. "Development and validation protocol for an instrument to measure household water insecurity across cultures and ecologies: the Household Water InSecurity Experiences (HWISE) Scale." *BMJ Open* 9 (1):bmjopen-2018-023558.

Young, S. L., Miller, J. D., Frongillo, E. A., Boateng, G. O., Jamaluddine, Z., Neilands, T. B., and the HWISE Research Coordination Network (2021). Validity of a Four-Item Household Water Insecurity Experiences Scale for Assessing Water Issues Related to Health and Well-Being. *The American Journal of Tropical Medicine and Hygiene* 104, 1, 391-394, available from: <https://doi.org/10.4269/ajtmh.20-0417>, [Accessed 04 February 2021]

- 1
2
3 Zeilhofer, Peter, Liliana Victorino Alves Corrêa Zeilhofer, Edna Lopes Hardoim, Zoraidy Marques
4
5 de Lima, and Catarina Silva Oliveira. 2007. "GIS applications for mapping and spatial
6
7 modeling of urban-use water quality: a case study in District of Cuiabá, Mato Grosso,
8
9 Brazil." *Cadernos de Saúde Pública* 23:875-884.
10
11
12 Zhou, J., Yang, F., Huang, Y., Ding, W. & Xie, X. 2020. Smartphone-powered efficient water
13
14 disinfection at the point of use. *NPJ Clean Water* 3, 1-9.
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

ACKNOWLEDGEMENTS

We would like to thank Dr. Zhuping Sheng for the invitation to participate in this special issue.

We acknowledge the U.S. National Science Foundation grants that supported our work:

Household Water Insecurity Experiences Research Coordination Network (HWISE RCN) (Award BCS-1759972), Coevolution of social and physical infrastructure and improved access to clean water in informal water sharing system (Award GCR-2021147), Nanosystems Engineering Research Center on Nanotechnology-Enabled Water Treatment (EEC-1449500) and the Lloyd’s Register Foundation (Grant #00068).

Box 1. Opportunities for geospatial & mHealth approaches to household water insecurity

Perhaps the most significant opportunities for understanding the complexity of household water insecurity are in the multi-scalar integration of geospatial and mHealth approaches. Household- and individual-level experiences of water insecurity are not yet rigorously linked to the regional socio-environmental processes that shape them. Geospatial frameworks can enable household and individual experiences to be contextualized using an increasing number of publicly-available global data sets of population density, economic development, land cover classes, climate, forest loss, and other regional-scale population and environment processes (Kugler et al. 2019). Efforts to link deforestation or watershed conservation activities to drinking water quality (Tellman et al. 2018, Mapulanga and Naito 2019), or to urban water security more generally (Mukherjee, Bebermeier, and Schütt 2018), have begun to advance these cross-scale linkages. By applying these approaches at the household level and with the resolution of mHealth application data, we can better understand how regional policies shape household water insecurity.

Box 2. Harnessing the mobile phone network using Smart Handpumps

The “Smart Handpumps” project is one example of a number of recent advances in the remote monitoring of rural water systems (Thomson, 2020). A “Smart Handpump” is a pump retrofitted with a low-cost accelerometer, microprocessor, and modem. Monitoring the slow movement of the handle produces hourly data on pump use and functionality and transmits this over the mobile phone network (Thomson et al. 2012). This information can be used by rural service

providers to dispatch a mechanic to make rapid repairs, and by local government to monitor service delivery. The accelerometer also tracks the faster handle vibration data. By applying machine learning to this data stream, we can also monitor the pump’s condition, alerting mechanics to a deteriorating pump before it fails (Greeff et al. 2019). This can eliminate pump downtimes and thereby reduce the need for communities to switch to unsafe alternative water sources.

For Peer Review

Figure 1. The Household Water Insecurity (HWISE) approach to advancing water security

