

Research Paper

Is household water insecurity a link between water governance and well-being? A multi-site analysis

Joshua D. Miller, Jaynie Vonk, Chad Staddon and Sera L. Young

ABSTRACT

Improving water governance is a top priority for addressing the global water crisis. Yet, there is a dearth of empirical data examining whether better water governance is associated with lower water insecurity and improved well-being. We, therefore, pooled household data from two Sustainable Water Effectiveness Reviews conducted by Oxfam GB in Zambia ($n = 997$) and the Democratic Republic of Congo (DRC, $n = 1,071$) to assess the relationship between perceived water governance (using a 12-item indicator), water insecurity [using the Household Water Insecurity Experiences (HWISE) Scale], and four indicators of well-being: life satisfaction, drinking unsafe water, diarrhea, and resilience to cholera outbreak. Using generalized structural equation models controlling for wealth and primary water source, each point increase in water governance score was associated with a 0.69-point decrease in HWISE Scale scores. Good water governance was also directly associated with greater odds of life satisfaction (aOR 1.24) and lower odds of both drinking unsafe water (aOR 0.91) and severe cholera impact (aOR 0.92). Furthermore, the relationships between water governance and drinking unsafe water, diarrhea, and cholera impact were mediated by household water insecurity. Improving water governance has the potential to meaningfully impact entrenched public health issues through changes in water insecurity.

Key words | cholera, diarrhea, household water insecurity, sub-Saharan Africa, water governance, water quality

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INTRODUCTION

The global water crisis threatens to undermine progress in human health and socio-economic development (World Economic Forum 2019). Although issues with water quality, quantity, and accessibility are already highly prevalent

[e.g. an estimated 4 billion people currently experience severe water scarcity for at least 1 month of the year (Mekonnen & Hoekstra 2016)], they are expected to become even more widespread as a result of population increase, climate change, and persistent water infrastructure degradation (Gosling & Arnell 2016; Kummu *et al.* 2016; High Level Panel on Water 2018).

Poor water governance and inequitable resource distribution have increasingly been recognized as major contributors to this crisis (UNDP 2006; UNESCO &

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World Water Assessment Programme 2006; Porcher & Saussier 2019). Although a universal definition of good water governance is still lacking (Tortajada 2010), numerous public, private, and societal actors have declared achieving good water governance to be a top priority for the WASH sector (Lautze *et al.* 2011; USAID 2017). Water governance also features prominently in the Sustainable Development Goals (SDGs). Indeed, three of the eight targets for SDG 6 focus on improved water governance (UN Water 2018; Di Baldassarre *et al.* 2019).

Water governance, broadly conceived, comprises a 'range of political, social, economic, and administrative systems that are in place to develop and manage water resources and the delivery of water services at different levels of society and for different uses' (Tortajada 2010). Succinctly, governance considers the relations between those who govern and those who are governed. Fundamental elements of good water governance include accountability, transparency, and trust across all spatial scales, i.e. the nation, region, community, and household (Woodhouse & Muller 2017). Sultana & Loftus (2020) align good water governance with state recognition of the human right to water, although others (Staddon *et al.* 2012; Langford & Russell 2017) have noted difficulties with rights-based approaches, such as the often unmet challenge of making such approaches legally tractable. Numerous scholars have also identified adaptability and resilience, especially to climate-driven changes to the hydrosocial cycle, as essential components of good water governance (Kashyap 2004; Akamani 2016; Honkonen 2017). An emergent literature further argues that water governance structures must recognize diverse sociocultural relations to water and appropriately address entrenched power dynamics to prevent the implementation of technocratic approaches that may marginalize minority communities (Bakker & Morinville 2013; Wilson 2014; Wilson & Inkster 2018; Empinotti *et al.* 2019).

These multi-sectoral, multilevel conceptualizations vary across institutional structures, cultures, and water typologies, and are thus inherently difficult to quantify (Woodhouse & Muller 2017). A patchwork of water governance indicators, though, do exist, such as the Water Governance Assessment Tool (Bressers *et al.* 2013) and the Water Governance Indicator Framework (OECD 2018). Furthermore, social scientists have developed survey-based

approaches to measure specific components of governance, such as trust, accountability, information sharing, and autonomy (Pickles *et al.* 1998; Staddon 1999). These assessment tools, however, can be onerous to implement because they require aggregation of quantitative and qualitative data across disparate disciplines and sources, from legal documents and financial reports to analysis of water managers' attitudes (Pahl-Wostl & Knieper 2014; Araral & Wang 2015; OECD 2018). It is also difficult to comparably measure water governance because the components assessed by each tool are not universally applicable, are ambiguously defined (e.g. legal accountability of water sector officials) (Araral & Wang 2015), or have not been validated (Bertule *et al.* 2018). For these reasons, it is perhaps unsurprising that few studies have rigorously quantified water governance (Sehring 2009; Araral & Wang 2015; Klümper *et al.* 2017; Collignon *et al.* 2018). Further, to our knowledge, none have quantitatively explored the relationships between good water governance and its impacts on individual well-being.

Household water insecurity is the inability to access and benefit from adequate, reliable, and safe water for well-being and a healthy life (Jepson *et al.* 2017). Although there is conceptual overlap between water governance and water insecurity, as well as theorized pathways linking improved governance to improved water security, the two are sometimes conflated (Klümper *et al.* 2017) or not considered jointly (Cook & Bakker 2012; Wutich *et al.* 2017). This is, in part, due to disciplinary siloing; hydrologists and policy-makers often consider community- or societal-level factors (e.g. water governance at the basin scale), whereas social scientists often measure household- or individual-level outcomes (e.g. water security at the personal or family scale) (Bakker & Morinville 2013; Ringler & Paulo 2020). It is increasingly recognized, particularly among socio-hydrologists (Mao *et al.* 2017; Di Baldassarre *et al.* 2019), that multilevel, integrated analyses are required to understand if and how improved water governance impacts human capabilities (Norman *et al.* 2013; Wutich *et al.* 2017).

The joint consideration of water governance and household water insecurity is important because water insecurity may be a pathway through which poor water governance impacts human health. It is commonly held that improvements in the maintenance, management, and control of

watersheds or water supply networks will maximize output, streamline and increase water treatment efforts, and protect against source interruptions, thereby producing a more reliable flow and reducing the frequency of shutoffs. A more efficient and better governed water supply network should, therefore, increase overall water availability, expand access, and improve water quality, all of which are critical components of household water security (Grey & Sadoff 2007; Bakker & Morinville 2013). As such, good water governance is expected to increase household water security (Wutich & Brewis 2014).

Greater household water security is associated with improvements in human health. Previous qualitative work has demonstrated that water insecurity is linked to well-being through physical, psychosocial, nutrition, and economic pathways (Collins *et al.* 2018). Site-specific household water insecurity scales have also allowed researchers to empirically test these relationships and quantify their magnitudes of effect (Boateng *et al.* 2018b; Wutich & Ragsdale 2008). For instance, in Ethiopia, each one-point increase in household water insecurity was associated with 0.18-point increase in psychosocial distress (Stevenson *et al.* 2012). The previous work in rural areas of the post-communist region has also demonstrated that resource insecurities, including water insecurity, were strongly and repeatedly associated with indicators of dissatisfaction (Staddon 1999; Staddon 2001). These scales, however, lack cross-cultural equivalence, meaning that results cannot be compared across settings. The Household Water Insecurity Experiences (HWIE) Scale was therefore developed to equivalently measure the multiple components of water insecurity (adequacy, reliability, accessibility, and safety) across disparate cultural and ecological settings (Young *et al.* 2019a, 2019b). Early application of the tool has shown that household water insecurity is positively associated with perceived stress and food insecurity (Young *et al.* 2019a). This tool, however, has not yet been used to explore relationships with water governance or other outcomes of public health interest.

We therefore sought to fill this knowledge gap by quantifying the relationship between water governance and household water insecurity. Specifically, we hypothesized that better water governance would be associated with lower household water insecurity. Our second aim was to

determine if water governance was associated with individual well-being, and if so, whether or not household water insecurity mediated the relationship. We hypothesized that better water governance would be associated with increased odds of overall life satisfaction and lower odds of drinking unsafe water, experiencing diarrhea, and severe cholera impact. We further hypothesized that household water insecurity would partially explain the effects of water governance on well-being, i.e. that water insecurity would mediate this relationship.

METHODS

Study design and setting

Data are drawn from two Sustainable Water Effectiveness Reviews completed by Oxfam Great Britain (Oxfam GB) during their 2018/19 financial year. Oxfam GB is an NGO that seeks to address the global challenge of water insecurity by working with development and humanitarian communities to achieve systemic change (Oxfam GB 2017). These reviews were designed to evaluate the impact and performance of two mature projects: 'Promoting the right to safe water, sanitation and hygiene (WASH) of peri-urban communities in Lusaka, Zambia' and the 'Sustainable WASH in Fragile Contexts (SWIFT) in DRC'.

In Zambia, the study area included three peri-urban communities (administrative subdivisions called 'compounds') – George, Chawama, and Kanyama –. These areas are characterized by dense, mostly informal settlement patterns where water access and management are ongoing challenges. Flooding, common during the wet season due to insufficient drainage, coupled with inadequate waste management, results in cyclical cholera outbreaks and other public health issues (Vonk 2019b).

In the Democratic Republic of Congo (DRC), the study area included 34 rural communities (i.e. villages) across 13 Health Areas (administrative divisions called 'aires de santé') in two health zones (administrative divisions called 'zones de santé') – Kirotshe and Mweso – in the southern part of North Kivu Province. These areas are remote, with households living approximately 1 h from the nearest market, on average, and livelihoods based largely on

agriculture and livestock. Safe and affordable access to water and sanitation services is an ongoing challenge (Vonk 2019b). Personal safety and security are under persistent threat, from ongoing disease outbreaks (including Ebola) and the presence of armed groups in the region, especially in Mweso (Asylum Research Centre 2019).

In both Zambia and DRC, Oxfam GB's interventions aimed to sustainably and equitably increase access to water and sanitation services and improve hygiene practices. Both projects ran for 4 years and were implemented by local partners. The approach of each project varied due to differences in context (e.g., urban vs. rural, local security conditions, and existing institutions). Briefly, in Zambia, the intervention focused on improving water and sanitation governance by educating citizens and engaging them with local government bodies and water service providers. It also promoted improved hygiene practices (Vonk 2019b). The project did not provide any physical infrastructure or services. The project in DRC took a more direct approach by repairing and installing water infrastructure, forming water management groups, managing capacity building activities, and promoting both latrine upgrades and construction. All activities in DRC were done in alignment with the national 'Healthy Village and Schools' (called VEA – 'Villages et Ecoles Assainis') approach (Vonk 2019a). More details can be found in the Supplementary Material, Table S1.

The sample size for each site was determined by the need to detect differences in key project outcomes by comparison versus intervention households. Sampling was stratified to achieve a 2:3 ratio of intervention and comparison households to allow for propensity score matching. As such, the sampling frame in Zambia included all households located within the three communities, with a target sample size of 200 households each in George and Chawama (intervention communities) and 600 households in Kanyama (comparison community). In DRC, the sampling frame included all households located in 14 intervention and 20 comparison villages, with a target sample size of 30 households per village (i.e. 1,020 households in total). Ultimately, 997 individuals were interviewed in Zambia and 1,071 in DRC, such that the final analytic sample was 2,068 individuals across both sites. This paper presents secondary analysis based on these data and does not evaluate project impact.

Within each community, households were sampled using a random walk protocol (United Nations Statistics Division 2005). Enumerators began from the approximate center of the community, spun a pen to indicate which direction to walk, and selected households based on a pre-determined random interval. Within each household, enumerators asked to interview an adult member of the specified gender (randomly indicated by SurveyCTO, the electronic survey software used for data collection) who was knowledgeable about the household's water and sanitation situation. If a suitable respondent did not exist or was unavailable for more than 1 day, enumerators interviewed a respondent of another gender, if possible. In the case of refusal, or if a suitable respondent could not be found after two attempts, enumerators recorded the reason for no interview and moved on to the next household in the pre-determined sequence. Data were collected during the dry season at each site to ensure that floodwaters did not prohibit access to certain households and thereby reduce or otherwise bias our sample.

Questionnaires were developed in English and then professionally translated into local languages (Nyanja and Bemba in Zambia, French and Swahili in DRC). Each survey item was reviewed by local enumerators (contracted and managed by an evaluation consultant) to ensure accurate translation and implementation fidelity. Survey data were collected using digital survey forms on mobile Android devices. Questionnaires differed slightly between Zambian and DRC study sites, although both included modules on socio-demographic characteristics, water and sanitation services, experiences with household water insecurity, attitudes toward water providers, the function and accessibility of water sources, and health and well-being (Supplementary Material).

Water governance

A novel water governance metric was created by dichotomizing and summing responses to 12 items that capture multiple components of water governance, including trust in and perceived equity, transparency, accountability, and adaptability of the current water system (Table 1). Scores range from 0 to 12, with higher scores indicating greater

Table 1 | Items included in a composite metric of water governance, by water governance component

Water governance component	Survey item(s)
Trust	1. How much would you say you trust water providers? ^a
Equity	2. Are the water needs of all people being met? ^b (Respondents are probed to consider the needs of women, children, and individuals with disabilities)
Transparency	3. Do you get any information about the management of your water and/or sanitation systems? ^b 4. Do you know who makes the decisions about your water services/systems? ^b 5. Do you understand how decisions are made for your water services/systems? ^b 6. Do you know who you can go to if you have questions or concerns about your water system? ^b
Accountability	7. What do you think you can do to hold the government and service providers accountable for water and sanitation services? ^c 8. How confident do you feel about your ability to hold the government and/or service providers accountable for water and sanitation services? ^a
Adaptability	9. How confident are you in the capacity of water/sanitation committees to manage routine maintenance to avoid breakdowns? ^a 10. How confident are you in the capacity of water/sanitation committees to implement major repairs after a breakdown? ^a 11. How confident are you in the capacity of water/sanitation committees to manage water systems through a crisis, shock, or disaster? ^a 12. How confident are you in the capacity of water/sanitation committees to make a full replacement of water systems if the current systems cannot be repaired? ^a

^a'not at all' = 0; 'just a little', 'somewhat', 'a lot/very' = 1.

^b'no' = 0; 'yes' = 1.

^c'do not know what to do', 'not sure about any rights' = 0; described any method for holding providers accountable = 1.

perceived functionality and equitability of current water systems, i.e. better water governance.

Household water insecurity

Household water insecurity was measured using the 12-item Household Water Insecurity Experiences (HWISE) Scale, which has been validated for use in low- and middle-

income countries (Young *et al.* 2019a, 2019b). Individuals were asked to report how frequently they or any household members experienced problems with water in the prior month. Scores range from 0 to 36, where higher scores indicate greater water insecurity.

Well-being

Respondents in both study locations were asked to rank their overall life satisfaction, from 'very dissatisfied' (scored as 1) to 'very satisfied' (4). These responses were dichotomized as 'unsatisfied' (0) and 'satisfied' (1). Respondents were also asked if they experienced diarrhea or if anyone in their household drank water they thought to be unsafe in the prior month; 'no' was scored as 0, 'yes' was scored as 1. Finally, in Zambia only, individuals were asked to compare the severity of the most recent cholera outbreak (which had occurred in the year prior to data collection) to other outbreaks in the past. Responses were dichotomized as 'affected about the same or less' (scored as 0) and 'affected more severely' (scored as 1).

Potential covariates and confounders

Socio-demographic information included respondent gender, marital status, education, and household size. Individuals were also asked to indicate community groups they actively participated in, such as water committees and religious groups. A household wealth index was derived from a principal component analysis of self-reported asset ownership (e.g. furniture, livestock, and equipment) and housing conditions (including materials and access to basic infrastructure) following best practices (Filmer & Pritchett 2001). This is a preferred method that overcomes known limitations and biases associated with self-reported income and earnings (Moore *et al.* 2000; Filmer & Pritchett 2001; Kim & Tamborini 2014). Wealth scores were then divided into quintiles and treated as an ordinal variable, where 1 represents the lowest relative wealth and 5 represents the greatest. Finally, individuals were asked which source their household primarily used for drinking water and the associated roundtrip collection time. This information was used to classify household water sources as 'unimproved' (unprotected well or spring), 'limited' (improved source

and collection time that exceeds 30 min), and 'basic' (improved source and collection time no longer than 30 min), in accordance with the Joint Monitoring Programme's drinking water service ladder (World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) 2017).

Missing data and multiple imputation

Water governance scores and HWISE Scale scores were missing for 15.5% and 7.6% of respondents, respectively (Supplementary Table S2). All other outcomes and potential covariates had 0–2% missing values. To minimize the bias that can be introduced in complete-case analysis (Sterne *et al.* 2009), especially in mediation analyses (Fairchild & McDaniel 2017), we assumed that data were missing at random and used multiple imputation to generate values for each variable across all sampled participants. We used multiple imputation using chained equations (MICE) to impute binary variables with logistic regression and ordinal variables with ordinal logistic regression (Royston & White 2011). To prevent out-of-range values for key predictor variables (water governance and HWISE Scale scores), we used predictive mean matching (Royston & White 2011). Imputation models included all variables in the analytic models and auxiliary variables. Auxiliary variables were those associated with either a different variable that had a large portion of missing cases or with the probability of missingness in that variable. Auxiliary variables included feeling so unwell in the prior month that normal activities were impaired, diarrhea in the prior month, respondent educational level, and whether the respondent participated in community groups.

We imputed 50 datasets to minimize sampling variability from the imputation process (Sterne *et al.* 2009). To evaluate the plausibility of the imputed data, we performed each analysis using the original dataset with missing values (i.e. complete-case analysis) and the imputed datasets. Both analyses gave similar results (i.e. direction of associations and significance at $p < 0.05$) and differed only in the magnitude of coefficients. We report results from multiple imputation as our primary results; results from complete-case analysis are included in Supplementary Tables S3–S5.

Statistical analysis

Descriptive statistics (chi-square, *t*-tests) were first performed to identify differences by study site. Best practices for mediation analysis were then followed to quantify the direct and indirect effects of water governance on individual well-being (Fairchild & McDaniel 2017). First, we regressed household water insecurity on water governance and all potential confounders to determine whether a significant relationship existed between the independent and mediating variable (Aim 1). To establish the significant relationships between the independent and outcome variables (Aim 2), we built logistic regressions that included water governance and potential confounders for each well-being outcome: overall life satisfaction, drinking unsafe water in the prior month, diarrhea in the prior month, and relative impact of the most recent cholera outbreak. Finally, to understand the potential complex relationships between water governance, water insecurity, and individual well-being, we developed multilevel generalized structural equation models (GSEMs) for each outcome. Multilevel GSEMs were built based on *a priori* pathways, that is, water governance influencing individual well-being both directly and indirectly through household water insecurity, accounting for the hierarchical structure of the data (i.e. individual responses nested within each site). We developed multiple models that included potential confounders both independently and jointly. The Bayesian information criterion (BIC) was used to select salient potential confounders and develop parsimonious models (Burnham & Anderson 2004). All analyses were completed using Stata 14.0 (StataCorp, College Station, TX, USA) at a significance level of 0.05.

Ethics

Enumerator training covered research ethics, including informed consent and data privacy. All participants provided verbal informed consent at enrollment. All data processing followed Oxfam's protocols for the ethical use of personal data (Oxfam International 2015) and was done in compliance with the General Data Protection Regulation (Vonk 2019c).

RESULTS

Sample characteristics

In total, 2,068 individuals were ultimately interviewed across both study sites. A nearly 1:1 ratio of males to females was achieved (52.5% females in Zambia, 48.5% in DRC; Table 2). Most socio-demographic characteristics and indicators of well-being differed by study site (Table 2). For instance, a majority (77.5%) of respondents in Zambia completed secondary school or higher, while a majority (68.8%) of respondents in DRC had no formal education. A greater proportion of respondents in DRC were also married compared to respondents in Zambia

(80.9% vs. 54.7%; $p < 0.001$). Additionally, the majority of respondents in Zambia (80.7%) primarily used a basic drinking water source, while over one-third of respondents in DRC (33.8%) reported using an unimproved drinking water source. In regards to the independent variables of interest, individuals in DRC reported better water governance than those in Zambia [mean (sd), 8.2(2.9) vs. 5.6(2.6); $p < 0.001$], although respondents from both sites reported, on average, similar levels of household water insecurity [10.2(10.6) vs. 10.9(9.7) in DRC and Zambia, respectively; $p = 0.136$].

Scale reliability

Cronbach's alpha for the water governance metric and HWISE Scale was 0.82 and 0.97, respectively, indicating high internal consistency (i.e. items reliably measured the underlying construct) (Tavakol & Dennick 2011).

Total effect of water governance

To determine the overall effect of water governance on household water insecurity and individual well-being, we developed multivariable regression models (Table 3). In a linear regression controlling for potential confounders,

Table 2 | Respondent and household characteristics, by study site ($n = 2,068$)

	Zambia ($n = 997$)	DRC ($n = 1,071$)	p -value
Female respondent (%)	52.5	48.5	0.069
Education of respondent (%)			<0.001
No formal education	5.2	68.8	
Primary school	17.3	23.4	
Secondary school	77.5	7.8	
Respondent married (%)	54.7	80.9	<0.001
Female household head (%)	23.3	19.1	0.020
Household size (%)			<0.001
3–5	55.6	45.5	
6–8	25.8	35.7	
9 or more	4.7	12.0	
Drinking water service level (%)			<0.001
Unimproved	4.6	33.8	
Limited	14.6	24.7	
Basic	80.7	41.5	
Household water insecurity (0–36), mean (sd)	10.9 (9.7)	10.2 (10.6)	0.136
Water insecure (HWISE Scale score ≥ 12) (%)	39.2	40.4	0.583
Water governance (0–12), mean (sd)	5.6 (2.6)	8.2 (2.9)	<0.001
Satisfied with life (%)	42.5	17.3	<0.001
Drank unsafe water in the prior month (%)	45.4	39.4	0.006
Diarrhea in the prior month (%)	25.9	27.6	0.366
Recent cholera outbreak more impactful than previous (%)	60.9	—	—

Table 3 | Multivariable regressions of household water insecurity and well-being on water governance in Zambia and DRC^{a,b}

	β	95% CI	p -value
Household water insecurity	−0.85	(−1.01, −0.69)	<0.001
	aOR ^c	95% CI	p -value
Well-being outcomes			
Satisfied with life ($n = 2,068$)	1.24	(1.19, 1.30)	<0.001
Drank unsafe water in the prior month ($n = 2,068$)	0.84	(0.82, 0.87)	<0.001
Diarrhea in the prior month ($n = 2,068$)	1.00	(0.97, 1.04)	0.821
Recent cholera outbreak more impactful than previous ($n = 997$, Zambia site only)	0.90	(0.86, 0.95)	<0.001

^aResults from complete-case analysis are available in Supplementary Table S3.

^bControlling for respondent education, marital status, household size, and site.

^cAdjusted odds ratio.

each one-point increase in water governance score was associated with a 0.85-point decrease in HWISE Scale scores (i.e. lower household water insecurity).

In logistic regressions controlling for potential confounders, water governance was associated with life satisfaction, drinking unsafe water in the prior month, and relative cholera outbreak severity, but not diarrhea in the prior month. For example, each one-point increase in water governance score was associated with a 16% decrease in the odds of drinking water perceived to be unsafe in the prior month (Table 3).

Mediation analysis

Each model to test mediation included water governance, household water insecurity, and an indicator of individual well-being. Although water governance was not independently associated with diarrhea in the prior month, a model with diarrhea was built because there are instances in which a predictor is not associated with an outcome but is significantly associated with a mediator, which in turn is significantly associated with the outcome (Fairchild & McDaniel 2017). Models controlling for wealth and drinking water service level provided the best model fit (based on BIC) and are thus presented here.

Greater water governance was associated with lower household water insecurity, even when controlling for wealth and water service level (Table 4). In multilevel GSEMs, each point increase in water governance score was associated with a 0.69-point decrease in HWISE Scale scores. Additionally, individuals using a limited or basic drinking water source were predicted to score 2.71 and 6.43 points lower, respectively, on the HWISE Scale compared to individuals primarily using an unimproved drinking water source.

Across both study locations, water governance was associated with individual well-being through both direct and indirect pathways (Table 4). In regards to direct pathways, each one-point increase in water governance score was associated with a 24% increase and a 9% decrease in the odds of reporting life satisfaction or drinking unsafe water in the prior month, respectively (Figure 1(a) and 1(b) and Table 4). There was no significant direct relationship between water governance and diarrhea in the prior month (Figure 1(c) and Table 4). Household water

Table 4 | Multilevel generalized structural equation models demonstrating the relationships between water governance and well-being among individuals in Zambia and DRC, both directly and as mediated through household insecurity, controlling for wealth and drinking water service level ($n = 2,068$)^a

	β	95% CI	p-value
Household water insecurity			
Governance	-0.69	(-0.85, -0.53)	<0.001
Drinking water service level			
Limited	-2.71	(-4.32, -1.11)	0.001
Basic	-6.43	(-7.89, -4.97)	<0.001
Wealth quintile			
Low	1.79	(0.30, 3.27)	0.018
Moderate	2.86	(1.34, 4.37)	<0.001
High	2.52	(1.04, 3.99)	0.001
Highest	0.73	(-0.73, 2.18)	0.329
	aOR^b	95% CI	p-value
Well-being outcomes			
Satisfied with life			
Governance	1.24	(1.18, 1.29)	<0.001
Household water insecurity	0.99	(0.98, 1.00)	0.070
Drank unsafe water in the prior month			
Governance	0.91	(0.87, 0.96)	<0.001
Household water insecurity	1.26	(1.23, 1.29)	<0.001
Diarrhea in the prior month			
Governance	1.01	(0.98, 1.05)	0.503
Household water insecurity	1.01	(1.00, 1.02)	0.005

^aResults from complete-case analysis are available in Supplementary Table S4.

^bAdjusted odds ratio.

insecurity was also directly associated with well-being; greater water insecurity was associated with greater odds of both drinking unsafe water and having diarrhea in the prior month, but not self-reported life satisfaction (Table 4).

Water governance was also indirectly associated with greater well-being. For instance, each one-point increase in water governance score was associated with a 1% decrease in the odds of diarrhea in the prior month, as mediated through lower water insecurity.

In Zambia, good water governance was also associated with lower odds of being impacted more severely by cholera (Table 5). Each one-point increase in water governance was directly associated with an 8% decrease in the odds of reporting that the most recent cholera outbreak was more impactful than the previous one (Figure 1(d)). Each

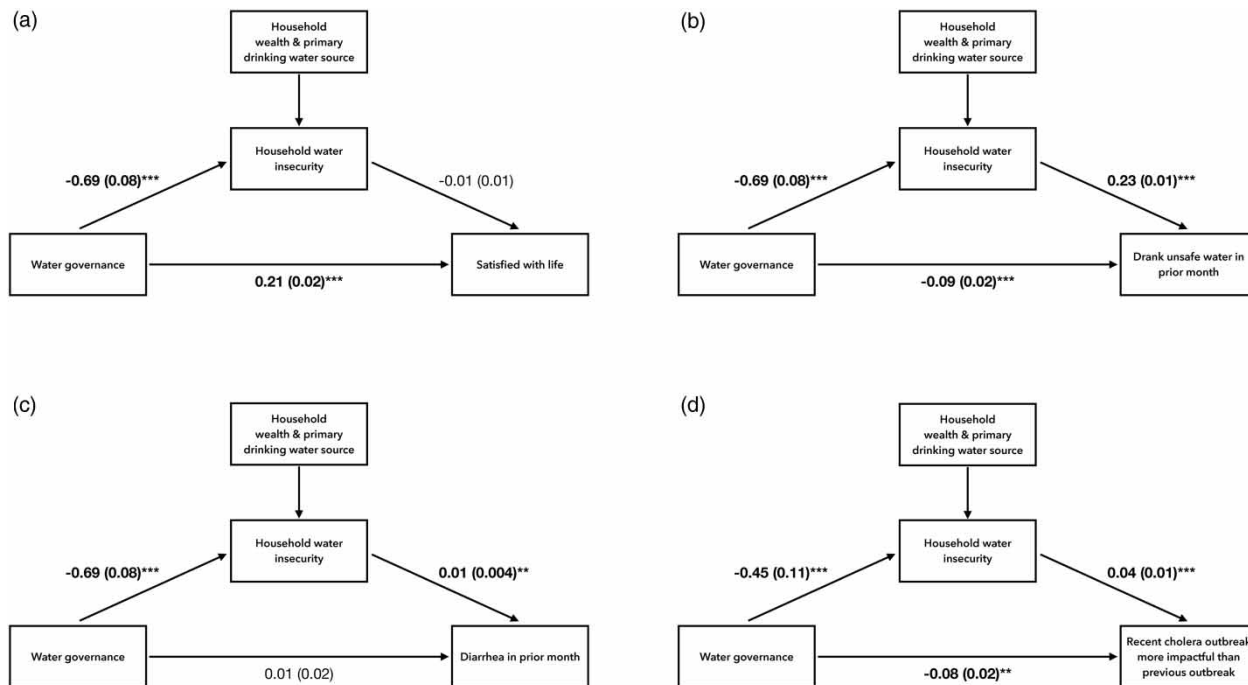


Figure 1 | Direct and indirect effects [β (SE)] of water governance on (a) life satisfaction, (b) drinking unsafe water, and (c) diarrhea among individuals in DRC and Zambia ($n = 2,068$). Direct and indirect effects [β (SE)] of water governance on (d) relative impact of most recent cholera outbreak among individuals in Zambia ($n = 997$). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 5 | Generalized structural equation models demonstrating the relationships between water governance score and relative cholera impact in Zambia, both directly and as mediated through household insecurity, controlling for wealth and drinking water service level ($n = 997$)^a

	β	95% CI	p-value
Household water insecurity			
Governance	-0.45	(-0.67, -0.23)	<0.001
Drinking water service level			
Limited	-1.00	(-4.54, 2.55)	0.582
Basic	-0.29	(-3.66, 3.09)	0.867
Wealth quintile			
Low	0.37	(-1.71, 2.45)	0.727
Moderate	1.63	(-0.47, 3.73)	0.129
High	0.08	(-1.93, 2.08)	0.208
Highest	-1.24	(-3.23, 0.75)	0.223
	aOR^b	95% CI	p-value
Recent cholera outbreak more impactful than previous			
Governance	0.92	(0.88, 0.97)	0.001
Household water insecurity	1.04	(1.02, 1.05)	<0.001

^aResults from complete-case analysis are available in Supplementary Table S5.

^bAdjusted odds ratio.

one-point increase in water governance was also indirectly associated with a nearly 2% decrease in the odds of reporting that the most recent cholera outbreak was more impactful.

DISCUSSION

In this first concurrent quantitative analysis of water governance, household water insecurity, and individual well-being, we sought to characterize the relationship between each of these phenomena and the pathways through which they might interact. Drawing on data from 2,068 individuals in Zambia and DRC, we demonstrated that better water governance (i.e. greater perceived functionality and equitability of current water systems) was associated with lower household water insecurity (Tables 3–5). We also found that good water governance was significantly associated with indicators of individual well-being, i.e. drinking unsafe water, diarrhea in the prior month, and relative impact of cholera, both directly and mediated through household water security.

To our first aim, we found that good governance was negatively associated with household water insecurity (Table 4). Although previous qualitative and theoretical literature has described good water governance as a critical determinant of water security (Wutich & Brewis 2014; Gerlak *et al.* 2018; Porcher & Saussier 2019), our study is the first to quantitatively assess the relationship between these two complex phenomena.

Our results demonstrating a significant relationship between water governance and water insecurity align with previous work conducted in the post-communist countries of Eastern Europe. There, it was found that indicators of good governance, such as trust in local and central government, trust in news media, and personal participation in environmental management, were positively correlated with better environmental services, including access to water (Pickles *et al.* 1998; Staddon 1999; Staddon 2001). Our findings are in contrast, however, to work in China by Aranal & Wang (2015), who found no significant correlations between measures of water governance (e.g. level of centralization of water law) and drinking water adequacy. Differences in level of analysis and operationalization of concepts may explain these divergent findings. First, we used a composite measure that included multiple components of water governance (e.g. equity and transparency), while Aranal & Wang (2015) examined individual components. Our water governance indicator was also developed based on users' perceptions, while Aranal and Wang's operationalization was based on water laws, policies, and administration. Additionally, Aranal and Wang created a province-level indicator of drinking water adequacy that aggregated information about the proportion of the population with access to piped water and overall water quality; we used a household-level metric of water insecurity that not only considers water adequacy but also reliability and use (Young *et al.* 2019a).

Our second aim was to explore the relationship between water governance and individual-level health and well-being. In relation to mental health, we found that increased water governance scores were associated with a greater likelihood of reporting general life satisfaction – a phenomena that is significantly associated with mental well-being (Pavot & Diener 2008). This occurred directly but not indirectly (Table 5 and Figure 1), meaning that water

insecurity did not mediate the relationship between water governance and self-reported life satisfaction. This aligns with previous research in Ethiopia, which found no significant relationship between increased access to improved water sources and psychological distress (Stevenson *et al.* 2016). It is important to note that water system improvements are different from improvements in water governance. Governance encompasses how providers engage with water users in relation to formalized or implied 'hydrosocial contracts' (Staddon *et al.* 2017), which extend beyond mere physical infrastructure (Tortajada 2010; Bakker & Morinville 2013; Empinotti *et al.* 2019). Our finding that decreased household water insecurity is not significantly associated with improvements in life satisfaction, although, could be seen as divergence from previous work that has found significant relationships between greater water insecurity and greater psychosocial stress (Wutich & Ragsdale 2008; Stevenson *et al.* 2016; Workman & Ureksoy 2017). General life satisfaction, however, is conceptually different from mental health, although psychosocial well-being is related to life satisfaction. Given that life satisfaction is a broad concept that includes physical, mental, financial, spiritual, and social well-being, it is perhaps unsurprising that there was no significant relationship between household water insecurity and reported life satisfaction.

We also found that better water governance was associated with two indicators of physical health (Table 5 and Figure 1). Although water governance was not directly associated with diarrhea in the prior month, it was indirectly associated with lower odds of experiencing it through decreased household water insecurity. Further, we found that each one-point increase in water governance score in Zambia was directly associated with an 8% decrease in the odds of reporting that the most recent cholera outbreak was more impactful than the previous one. It is possible that these improvements in health are in part related to a reduced likelihood of consuming pathogen-contaminated water. This is supported by the fact that improved higher water governance scores were associated with lower odds of drinking water perceived to be unsafe in the prior month (Table 5).

Given that diarrheal diseases and cholera are both major global health burdens (Ali *et al.* 2012; Jamison *et al.*

2017) and that water interventions have had variable success at reducing diarrhea prevalence (Arnold & Colford 2007; Luby *et al.* 2018), these consistent findings across diverse settings have important implications for water policy. Namely, these results provide an empirical basis for developing policies and programs that improve water governance and/or household water insecurity in order to address entrenched public health issues, including diarrhea and cholera. In contrast to more traditional infrastructure-based solutions, our findings suggest that ‘soft-path’ approaches (e.g. improvements in equitable water distribution, increased transparency about water management decisions) may be effective at improving proximal health outcomes (Gerlak *et al.* 2018). Indeed, water governance remained a significant predictor of water insecurity, even when controlling for drinking water source, suggesting that water quality and availability is necessary, but not sufficient, for water security. Indeed, our findings provide empirical support for Oxfam GB’s Sustainable Water and Sanitation Strategy (Oxfam GB 2017), which identifies good governance as a necessary precondition for good health and well-being. Further empirical research on this topic in other settings is needed and could provide additional evidence to support existing theoretical arguments about the need to prioritize good water governance.

This study is novel for its concurrent quantitative examination of multilevel phenomena, including water governance, household water insecurity, and individual well-being. There are, however, limitations that should be considered when interpreting results. Although the water governance indicator had high internal consistency, it was not designed following best scale development practices (Boateng *et al.* 2018a), as was done for the HWISE Scale (Young *et al.* 2019a). Indeed, the development and validation of a cross-culturally equivalent tool to measure water governance would be a very useful contribution to the field. Such a tool could be used to systematically evaluate the impact of water governance interventions and to determine if these findings are generalizable.

A further strength of this study is that it demonstrates that water governance is associated with improvements in individual well-being, both directly and indirectly through water insecurity. The associations within these pathways, however, should not be interpreted as causal. Future

longitudinal studies could expand upon this work to assess temporal relationships and explore if these relationships change across seasons. Additionally, the use of objective water quality indicators and biomarkers, e.g. stress and pathogen exposure, would help to better demonstrate how water governance impacts individual health. The use of a shorter diarrhea recall (i.e. prior few days instead of a month) may also reduce potential bias in this self-reported measure (Schmidt *et al.* 2011).

CONCLUSION

Perceived water governance was significantly associated with improved household water insecurity, which in turn was associated with improvements in household and individual well-being (lower odds of drinking unsafe water, lower odds of experiencing diarrhea, and decreased relative severity of cholera outbreaks). Ultimately, improvements in water governance hold promise for the improvement of both water insecurity and well-being, and further advancing progress toward the SDGs.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at <https://dx.doi.org/10.2166/washdev.2020.165>.

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