Research Paper

Infrastructure for water security: coping with risks in rural Kenya
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ABSTRACT
Achieving universal access to sufficient water is becoming more challenging as climate change exacerbates water insecurity. Previous studies of water insecurity and climate-related hazards recommend understanding how people perceive and manage water-related risks. By uniquely combining protection motivation theory and photovoice, we explore water infrastructure’s function in rural Kenyan households’ perception and mitigation of water-related risk. We find that infrastructure construction provides a sense of security, regardless of long-term management plans. During the dry season, built infrastructure’s viability to mitigate risk is strained due to natural infrastructure’s unreliability. In the context of limited built infrastructure, natural infrastructure, though unimproved, is necessary for water security. In the expected absence of large-scale infrastructure projects, for water authorities in rural Kenya, we recommend the construction of small-scale infrastructure to increase reliance upon rainwater harvesting and lessen the strain on other built infrastructure during the dry season. Coupling our method with an itemized scale can help explain discrepancies between actual insecurity and individuals’ responses to help water authorities predict interventions’ effectiveness and inform the division of responsibilities in policies intended to promote sustainable infrastructure management. We also recommend our method for assessing water infrastructure’s role among households managing multiple climate-related risks to expand infrastructure’s resilience.

Key words | climate change, Kenya, mitigation, perception, photovoice, protection motivation theory

HIGHLIGHTS
- Climate change exacerbates water insecurity in rural Kenya.
- What is the function of water infrastructure in households’ perception and mitigation of water-related risks?
- Protection motivation theory informs the division of responsibilities and predicts the sustainability of the long-term management of infrastructure in the face of climate change.
- PMT is well-paired with photovoice to capture the roles of infrastructure and are together a suggested companion for itemized scales.
- For water authorities in rural Kenya we recommend the construction of small-scale infrastructure to increase reliance upon rainwater harvesting and lessen the strain on other built infrastructure during the dry season.
INTRODUCTION

Progressing toward universal access to sufficient water is becoming increasingly challenging as climate change exacerbates water insecurity (Turral et al. 2011) and poorly resourced settings struggle to adapt (Balasubramanian 2018). Yet, development policymakers remain steadfast in their efforts to achieve universal access (World Health Organization & UNICEF 2011). To maintain progress in low- to middle-income countries (LMICs), it is critical to accurately identify and mitigate climate-related threats to water management. Accurate identification relies upon the documentation of the lived experiences of water insecurity; manifested at the household and individual levels (Young et al. 2019), these water burdens are insufficiently addressed by national or global policies informed strictly by aggregated progress indicators. In reality, water insecurity is comprised of subjective and objective experiences (Jepson et al. 2017) of uncertainty surrounding ‘the ability to access and benefit from affordable, adequate, reliable, and safe water for well-being and a healthy life’ (Jepson et al. 2017, p. 3). Therefore, comprehensively monitoring water insecurity requires examining these many components of water and their functions in terms of risk and its management at the levels they occur (Young et al. 2019).

At the leading edge of these monitoring efforts is the Household Water InSecurity Experiences Research Coordination Network (HWISE-RCN), which provides a tool to quantify household water insecurity across LMICs. This itemized scale can concurrently measure several dimensions of water insecurity, such as affordability and adequacy, to identify causes and effects of universal experiences of insecurity. In addition to deploying this quantitative survey tool, the HWISE-RCN also uses qualitative methods to capture households’ experiences of water insecurity, including details regarding households’ water acquisition, use, and storage (Young et al. 2019). Contributing to this excellent existing work, this paper focuses upon the qualitative methods involved in water insecurity monitoring. For these methods, we proffer a theoretical framework and participatory data collection method (Boateng et al. 2018) that, when paired, are uniquely positioned to elicit water infrastructure’s function in household water insecurity experiences. As a major component of water security, infrastructure influences most of the items within scales (e.g., frequency of interruptions of main water source (Young et al. 2019)), and its contribution to insecurity is typically represented within scales by proxies such as the quality of source and collection time (Stevenson et al. 2012). However, the complexity of engineering systems demands flexible and ‘hybrid approaches for constructing our knowledge of such systems’ (Bartolomei et al. 2009, p. 01). Constructing resilient water infrastructure depends upon diverse knowledge. This paper proposes using new qualitative techniques to provide fresh insights into how infrastructure – both the construction of manmade and performance of natural systems – conditions experiences of water-related risk and risk management. While not yet globally validated, our
study in rural Kenya is an appropriate beginning given the country’s climate-exacerbated droughts and variability in rainfall (Core Writing Team et al. 2007). Given the broad definition of the term infrastructure, we define it as technology in relation to organized practices, in this case to water collection and use (Star & Ruhleder 1996). This definition includes household tanks and gutters as infrastructure, as well as natural water bodies, as they are components of a water resource network (Marks & Davis 2012). We also define climate-resilient water infrastructure as systems that can resist, absorb, and recover from the effects of climate-induced stresses in a timely manner, ‘including through the preservation and restoration of its essential basic structures and functions’ (UNISDR 2009, p. 24).

Theory

We focus upon the function of water infrastructure (Young et al. 2019) in households’ water-related risk and risk management through the experience-based framework of protection motivation theory (PMT) (Rogers 1975; Maddux & Rogers 1985). This theory is a widely accepted framework describing the relationship between perception and mitigation of risk, a relationship we posit is conditioned by households’ perceptions of water infrastructure (Schlef et al. 2018). PMT is appropriate to our Kenyan context, as it has been exercised in recent studies on climate change in other sub-Saharan countries such as Burkina Faso (Schlef et al. 2018) and The Gambia (Bagagnan et al. 2019). According to PMT, individuals engage in protective mitigation behavior if the level of threat is considered to be high and if the coping strategy is anticipated to be effective, easy to implement, and low-cost (Rogers 1975; Maddux & Rogers 1985; Bubeck et al. 2015). That is, if individuals perceive a risk as being sufficiently probable and damaging, they may attempt to mitigate that risk only after assessing the effectiveness of the measure (its response efficacy), their ability to implement the measure (their self-efficacy), and the potential cost of the measure (its response cost). Among the limited relevant literature are studies which successfully use PMT to describe the relationship between slow-onset climate-related risk perception and mitigation at the household level (Grothmann & Reusswig 2006; Bubeck et al. 2015; Poussin et al. 2014; Keshavarz & Karami 2016; Bisung & Elliott 2018; Schlef et al. 2018). Several of these studies highlight how households experience infrastructure as they evaluate and manage risk. As expected, the cost of infrastructure designed to reduce risk (to flooding, for example) can be a barrier to its construction (Bubeck et al. 2015; Bisung & Elliott 2018). Interestingly, the more self-efficacious that households perceive themselves to be, the more infrastructural measures they implement (Poussin et al. 2014). In contrast, greater trust in public authorities and their risk protection measures results in fewer constructed infrastructural measures (Bubeck et al. 2015; Bisung & Elliott 2018). The mere installation of infrastructure can be associated with the perception of decreased risk (Poussin et al. 2014), regardless of the actual protection it affords. These studies highlight that the promise PMT holds for eliciting the complexities surrounding the construction and performance of infrastructure in households’ risk management.

Method

We use photovoice as our data collection method, for which participants were asked to take and discuss photographs of water-related uncertainty. We chose photovoice due to its prior success in capturing the experiences of disadvantaged populations with both water insecurity (Boateng et al. 2018) and infrastructure change (Kaminsky 2015). This technique is useful for enabling participants to describe and explain behavior related to water insecurity that ‘might be overlooked if a photographic image were not available for reflection’ (Bogdan & Biklen 2007, p. 151). The potential reduction in free recall bias and photography’s inherent strength of focusing attention upon visible artifacts such as infrastructure (Kaminsky 2015) are advantages of using photovoice over typical interview methods to study infrastructure that is often embedded in society and taken for granted.

In this paper, we offer a new qualitative method consisting of PMT and photovoice to be used in conjunction with itemized water insecurity surveys and scales such as those created by HWISE. With this method, we offer new insights into the following question: What is the function of water infrastructure in households’ perception and mitigation of water-related risk in rural Kenya?
METHODS

Setting and participants

This study is part of a larger water intervention study that occurred in 2015 and 2016 (Cook et al. 2016, 2018). We received an appropriate institutional review board approval in the USA and a research permit in Kenya prior to intervention commencement. In 2015, researchers from the University of Washington began a 2-year randomized-controlled trial to study the socioeconomic impact of reduced water collection time. Participants lived in four villages clustered around the small town of Kianjai in north-central Kenya, approximately 20 miles from the city of Meru. All selected households met the criteria of either (1) not having a well or piped water or (2) having at least one school-aged child at home (Cook et al. 2018). The researchers reduced water collection time by randomly assigning half of the households to receive water at their households from vendors for approximately the worst 8 weeks from August to October of a dry season. The households received coupons for free vended water with the expectation that this water would eliminate their need to collect water. On average, households received 60 coupons per week, or approximately 50 jerricans (20 liters each). The control households instead received commensurate household goods, such as cooking oil.

The person in each household who identified him- or herself as the primary water carrier and manager (henceforth, the water manager) was provided a smartphone with a time-use measurement app for recording water collection activities. Among the original study’s sample, this person was the one who had collected the most water in the past 7 days and who decided where to collect water and how much to collect (Cook et al. 2016). The typical water manager and household characteristics are consistent with the general demography of Kenya (73% of total population lives in rural regions; World Bank 2018). The typical water carrier and manager was a 37-year-old woman with 8 years of education (expected years of schooling is 11.7; mean is 5.7 years for Kenyan women; UNDP 2018). Almost all (98%) of the original sample of participants reported laboring on the household’s farm. Thirty-nine percent of the original sample worked for wages in the 2 weeks prior to being asked, working for 4.7 days over that period and earning an average daily wage of 250 Kenyan shillings (Ksh), or approximately USD 2.45 (~102 Ksh/USD in August 2016) (Cook et al. 2018). For context, the World Bank international poverty wage line is approximately USD 1.90 (FAQs 2015). Meru County is primarily characterized by agricultural productivity (Ministry of Agriculture Livestock & Fisheries Kenya 2016) and has two rainy seasons, one typically from mid-March to June and another from mid-October to early December. Mean annual rainfall for the area is approximately 54 inches (Cook et al. 2016).

Data collection

After this water intervention ended, participants faced a marked period of water access change and uncertainty. Water managers returned to paying for water collected primarily from shared wells, boreholes, or vendors. We availed ourselves of this abrupt change in access to capture the water managers’ potentially heightened sense of uncertainty, as evidenced by sentiments such as, ‘I did not have water problems at that time until when the project ended’ (Respondent 05, 2016), and ‘When water was supplied to my household...The stress of getting water was reduced because I didn’t depend on water vendors for water’ (Respondent 07, 2016). This change was an opportunity to uncover potentially subconscious behaviors, which is useful for studying perceptions around potentially invisible or taken-for-granted infrastructure (Kaminsky 2015).

Of the original sample, 20 households agreed to continue using the smartphones and were asked to photograph ‘what water-related uncertainty means to them’ for this project. We permitted seven control households to continue participating, as the benefits to their economic situation from the households goods, or being recipients of neighbors’ free vended water, suggested that these households were affected by the intervention terminating. A pilot study was conducted with four people, during which the limitations of interviewing in English were realized. The actual study lasted for 2 weeks, during which respondents were called and given reminders every 2 days.
After 2 weeks, semi-structured interviews were conducted and audio-recorded at participants’ households. Interviews were conducted in Kimera with the water manager and focused upon household water supply and each photograph. The interviewer primarily asked experience, behavior, and feelings questions; these question categories fit well with the PMT framework. Upon interview completion, participants were given cooking items worth 1000 shillings (10 USD) (M. Mwiti, personal communication, November 23, 2017). Participant consent was obtained for use of interview text and photographs. Given that the personal meaning of the photographs concentrates their utility to data collection, and given the low resolution of the photographs, the authors do not include them in the paper. Details on the coding of the photographs and the interview text may be found in Supplementary Table S1.

RESULTS AND DISCUSSION

In the results, we discuss how the extent to which water infrastructure contributes to risk and how risk management depends upon its construction and the season, the latter affecting the unique roles of the built and natural water infrastructure. We highlight the utility of our methods and the insight it provides to the data.

Construction: deferred responsibility and the immediacy of risks

The ability for infrastructure to mitigate risk depends not only on its construction but also on its long-term governance – the management of who gets water, when and how – and its connection to an institution (Kasperson & Kasperson 1996). Infrastructure’s viability as perceived by the water manager is similar, except for their interest in management. Most water managers merely want aid with the construction of water infrastructure and do not mention needing help with long-term governance (e.g., ‘If we get a donor to drill borehole for us...’ (Respondent 09, 2016); ‘...if the government could install piped water...’ (Respondent 14, 2016)). The urgency of water managers’ needs may naturally concentrate their attention on the anticipated immediate relief associated with water infrastructure construction, as opposed to distant relief which would require ongoing maintenance. In addition, households are often unable to start or successfully finish infrastructure projects themselves due to the costs associated with time and labor (e.g., ‘As I said there are so many people who have wells and they have not benefited from them because they are not deep enough. Unless those people who are able financially and are able to dig deeper into the ground to get the water’ (Respondent 04, 2016)). Apart from these high response costs often associated with private water infrastructure, the water managers also expect that the response efficacy of an infrastructural measure will increase automatically when a third party installs it (e.g., ‘I always imagine we will ever get a donor who will dig up a big public borehole that will have enough water to serve all people in our area...’ (Respondent 11, 2016)). Some water managers have witnessed prior successful water projects (e.g., ‘This is because I have seen public boreholes that have plenty of water...’ (Respondent 11, 2016)), which may strengthen their view of the potential of construction. This belief in construction may be sustained when infrastructure ceases to deliver water because participants may not think that the infrastructure itself has failed, but rather the third-party providers have failed in their duties (e.g., ‘...Poor water resource management in the area also contributes to this uncertainty because government and community leaders do less to curb the problem!’ (Respondent 12, 2016)). Shifting responsibility of risk mitigation has been found to lead to low self-efficacy with regard to water managers successfully taking their own protective measures against water-related uncertainty (Poussin et al. 2014; Bisung & Elliott 2016; Schlef et al. 2018). These low self- and response-efficacies – and the immediacy of water-related needs and decreased sense of risk felt with construction (Poussin et al. 2014) – appear to be self-perpetuating realities for many other rural and marginalized areas in Kenya, whose community water projects often cease functioning 3 years after installation due to poor governance and management (Water Services Regulatory Board (Wasreb) 2018). PMT is a useful framework for explaining and predicting the management of water infrastructure systems because it uniquely incorporates the self-efficacy of the users as a component of their coping appraisal (Floyd et al. 2000). Using PMT in water insecurity assessments along with an itemized scale can help explain...
discrepancies between actual insecurity and individuals’ responses to inform the division of responsibilities within infrastructure management policies. Clear communication of these responsibilities between water managers and water service providers is vital for sustainable infrastructure management (Grothmann & Reusswig 2006).

Seasonality: intensifying dry seasons and infrastructure types

To more fully apprehend the function of water infrastructure and to improve its climate-resilience, it is beneficial to examine how households experience risk and engage in mitigation behaviors differently during the dry and wet seasons. During rainy seasons, the water manager primarily modifies her water supply, choosing to ration and reuse less than she does during dry seasons (e.g., ‘This uncertainty is less during wet or rain season because washing of clothes is done frequently because there is enough water to wash since one can carry the clothes and wash them at the river...’ (Respondent 12, 2016)). Most households have storage tanks and/or gutters to tap rainwater, which is counted as a sufficient source of drinking water for the purposes of monitoring progress toward universal access (World Health Organization & UNICEF 2017): households perceive their water-related risks as low during the rainy season largely because they consider rainwater harvesting as an effective mitigation strategy (e.g., ‘We don’t face any water challenge during rainy seasons because we collect and store rainwater’ (Respondent 06, 2016)). Households also rely upon seasonally available natural infrastructure (e.g., ‘Wet season we tap rain water to use at home and also we have rivers have water and they are near so it’s easy collecting water and at this time we not have problem’ (Respondent 09, 2016)), which is primarily rivers in this study (Cook et al. 2016) but more broadly includes any existing environmental systems and their ecosystem services which provide and help circulate water (McCartney & Dalton 2015). Despite river water being considered an unimproved drinking water source (World Health Organization & UNICEF 2017), it plays a significant role with rainwater in reducing perceived and actual water insecurity during the rainy season. For example, as determined by the original study, during the rainy season total reported water collection times decrease by approximately 70% to a mean of 112 min/day (Cook et al. 2016). In contrast, built infrastructure (e.g., ‘The situation of water shortage is more common during dry seasons. This is because most boreholes run out of water’ (Respondent 06, 2016).) and natural infrastructure are both strained during the dry season, and households perceive their risk of water insecurity as high (e.g., ‘The impact is more certain during dry seasons because getting even little water is very hectic’ (Respondent 03, 2016)). Despite the drastic difference in seasonal risks, we believe that the temporal nature of the dry season and its challenges may create a protective sense of optimism that limits mitigation behaviors oriented toward the long-term management of insecurity, including the management of infrastructure. According to the previously cited PMT literature, prior experience of a risk may not be associated with households implementing additional mitigation measures or installing infrastructure intended to mitigate the risk (Bubeck et al. 2013; Poussin et al. 2014). Taken together, this literature may suggest that in our study, the seasonality and recurrence of water-related risks may not persuade water managers to invest more in long-term management of infrastructure (in addition to their short-term mitigation behaviors). Using photovoice helped to capture these unique seasonal roles of built and natural infrastructure, and coupled with PMT, assists in informing the long-term management of infrastructure as the temporal challenges of dry seasons become more constant.

Despite a lack of long-term management plans, water managers still engage in short-term mitigation behaviors that are intensified during the dry season to alter both supply- and demand-sides of water consumption, despite knowing these behaviors’ high response cost. Unlike in Schlef et al. (2016) and Grothmann & Reusswig (2006), low response efficacy and high response cost are not correlated with non-protective responses. For example, during the dry season, the water managers are willing to fetch dirty water despite the time cost (e.g., ‘During dry seasons, quantity of water coming from the tap drops hence cannot cater for the rising demands of water in the community...I am therefore forced to look for water from boreholes which are located very far from my home. However, borehole water is not as clean as piped water but I have to get the water no matter what’ (Respondent 03, 2016)).
associated with water insecurity (i.e. water is necessary for life) warrants coping to some degree; unlike non-protective responses to other climate-related risks such as floods (Schleif et al. 2018), non-protective behavior to water insecurity leads to loss of life. The appropriately elevated responsiveness to water-related risk may disable LMIC households from responding protectively to other climate-related risks; this situation will only heighten in regions such as Kenya as climate change increases drought conditions (Core Writing Team et al. 2007). By using PMT and considering its body of literature cited above, we are able to compare households’ responses to different types of climate-related risks and identify the opportunity for future research to continue to study how the same households perceive, order, and respond to a conflux of climate-related risks originating from disparate sources (e.g., from floods or wildfires) (Roba et al. 2019). This research might pair PMT with an itemized insecurity scale to help explain unexpectedly weak responses to objectively high levels of insecurity. In the absence of large-scale infrastructure projects (Godfrey & Hailemichael 2017), for similar rural Kenyan contexts, we suggest investments in non-piped household- or community-scale infrastructure such as tanks and gutters to increase households’ storage capacity and reliance upon rainwater harvesting and lessen the dependence upon natural infrastructure, which is more unreliable during the dry season. Rainwater harvesting may also decrease collection time and its associated economic costs (Cook et al. 2016) and child health impacts (Pickering & Davis 2012). Rainwater harvesting is found to be a viable strategy for rural households contending with climate-related water insecurity (Mwenge Kahinda et al. 2010). This strategy is relevant and aligns with the efforts of non-profits that install small-scale rural rainwater harvesting systems to promote food and water security (Results for Development (RD4) 2019). For long-term sustainability, we suggest that installation of these low-cost infrastructures be coupled with explicit management plans and risk education regarding non-piped sources (Kumpel et al. 2016).

CONCLUSION

Through this study, we describe how and why infrastructure contributes to and mitigates water insecurity, both perceived and actual, in rural Kenya. We find that the extent to which water infrastructure contributes to risk or risk management depends upon its construction, the season, and the type of infrastructure (natural versus built). Mere construction of built infrastructure provides a sense of security, regardless of the existence of long-term management plans. The viability of household adaptation strategies depends upon the season, most clearly indicated for infrastructure by the differing roles of built and natural infrastructure. Households rely heavily upon built infrastructure to mitigate risk during the dry season as a result of the unavailability of natural water infrastructure. In the context of limited built infrastructure, natural infrastructure, considered an unimproved water source, enables households to meet domestic needs beyond drinking water and thereby improve their water security. The potential for discrepancies between perceived and actual water insecurity – between self-reported and externally measured insecurity (Nounkeu & Dharod 2018) – as illustrated by households’ relationships to infrastructure construction, encourages the use of PMT as a framework for the qualitative component of water insecurity assessment. Through this case study, we demonstrate PMT and its body of literature as a useful framework for informing water insecurity interventions and policies, as it can help inform the division of responsibilities and predict the sustainability of the long-term management of infrastructure in the face of climate change. PMT is well-paired with photos and voice to capture the roles of infrastructure and are together a suggested companion for itemized scales.

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CONFLICTS OF INTEREST

None declared.
DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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