Understanding uptake of community groundwater monitoring in rural Brazil

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Resource monitoring is often cited as important for effective common pool resources management. In practice, not all monitoring interventions are successful, particularly when the resource, such as groundwater, is challenging to monitor and measure. We conducted a field experiment on groundwater monitoring in Ceará, Brazil, where communities are increasingly reliant on groundwater yet do not engage in monitoring. Despite careful implementation, uptake of monitoring within the 80 treatment communities was low. To unpack this low uptake, we conduct multimethods exploratory research. We find that uptake is less likely in communities facing high coordination costs, either within the community leadership or across the broader community. Uptake is also less likely when there are physical barriers to monitoring, when there are more substitutes for groundwater, and when there is lower variability in water availability. Our findings can inform future monitoring interventions in similar contexts worldwide.

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Successful common pool resource (CPR) governance often requires community coordination in monitoring resource use and sanctioning overuse (1). In the case of groundwater, where the coupled effects of climate change and overuse are depleting stocks globally (2), monitoring is critical for equitable management (3), particularly by citizens (4). Nevertheless, groundwater monitoring is limited and often inadequate in much of the world (5). We focus our study in the state of Ceará in Brazil's driest region, the northeast (6). Despite recent droughts that increased the human population's reliance on groundwater, monitoring and management of groundwater are limited and only implemented for the largest wells (7, 8).

We conducted a field experiment on groundwater monitoring with rural communities in Ceará. As part of a series of harmonized studies, we estimated the effects of monitoring on water use, user satisfaction, and user knowledge and stewardship attitudes. Despite careful execution of treatments and comprehensive data collection, we did not detect any effects of monitoring on prespecified outcomes (9), which we attribute primarily to low uptake of the intervention.

To understand uptake in our context, we synthesize a framework from the CPR literature and validate it with detailed field data from our intervention. Theory suggests that users weigh the costs and benefits of monitoring and substitutes for the resource when choosing whether to monitor the CPR (1).

We define three categories of costs relevant to CPR monitoring in our context: 1) coordination costs incurred when coordinating the community's CPR monitoring efforts and disseminating and responding to information collected via monitoring; 2) monitor costs incurred by monitors, which include time, effort, and monetary outlays; and 3) physical barriers that raise the costs of observing the state of the CPR.

The benefits of CPR monitoring pertain to resource access. Communities where resource access is more limited or uncertain may perceive greater benefits of CPR monitoring.

Substitutes are alternative options that reduce the salience of the resource or diminish vulnerability to fluctuations. By providing additional means of accessing the resource external to the CPR system or smoothing risk in case of resource scarcity, substitutes dampen the benefits of CPR monitoring.

We conduct exploratory multimethods research by combining baseline household surveys, implementation questionnaires, precipitation records, and qualitative interviews. We use an elastic net logistic model with cross-validation to identify which variables are most influential in predicting uptake of monitoring, and we compare the results to a content analysis of the interview transcripts. We find evidence that coordination costs, monitor costs, physical barriers, resource benefits, and substitutes predict uptake of an external monitoring intervention by communities in our context.

Context and Design

Communities in the study area use a mix of water supply sources, including small communal wells. Groundwater use in these wells is not regulated by the government (8). Often, a community association (CA) manages the water distribution system informally (i.e., lacks legal authority) and a water "operator" maintains it (10). We randomly selected 10 municipalities in Ceará from a set that met geological, governance, and size specifications. Within these municipalities, we randomly selected 120 rural communities that had an active CA, an operator, and a functional well at baseline (*SI Appendix*).

We executed a monitoring intervention field experiment where communities received training to monitor electricity use directly associated with groundwater pumping and, if community wells were openable, depth to water.* We randomly assigned† 80 communities to one of two treatments (T1‡ or T2) and 40 communities to neither (Control). T1 was always executed in conjunction with the existing CA and water operator but was presented as an externally designed and facilitated monitoring intervention.§ T1 consisted of 1) a full-day community workshop

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*In the original experiment, we measured effects of monitoring on water use, satisfaction, knowledge, and stewardship using baseline (pretreatment) and endline (posttreatment) survey data.

†Random assignment occurred in blocks based on pretreatment community-level water insecurity.

‡T1 was harmonized across a variety of research contexts as part of a Metaketa initiative.

§Users with prior organizations and leadership are more likely to engage in CPR management (1).

Fig. 1. Proportion of 80 treatment communities that sent monitoring data to the research team in each month of the study period. Workshops began in May 2018 and were completed by August 2018. The last month that the intervention was underway in all communities was June 2019.

facilitated by members of the research team; 2) the creation and training of a Water Committee to conduct the monitoring; and 3) communication with the research team to share collected data via WhatsApp. T2 received T1 plus monthly household visits by Water Committee members to discuss household water use.

We use WhatsApp submission records to construct a binary measure of uptake with the value of 1 if monitors in that community sent any messages with collected data during the intervention period (June 2018 to June 2019) and a value of 0 if not.[¶] Despite careful execution of the workshops, there was low initial uptake of the monitoring intervention and a decline over time (Fig. 1). The training workshops took place between 24 May and 29 July 2018. Uptake was highest in the third month of the intervention period (August 2018), at just under 30% of treatment communities.

We conduct two pieces of exploratory analysis to explain the low uptake of the monitoring intervention. First, we follow Zou and Hastie (11) to use elastic net regularization with repeated k-fold cross-validation to explore the predictors of treatment uptake. The outcome variable in the elastic net models is the community-level binary uptake variable. We identify a set of 30 predictors (p) that proxy for costs, benefits, and substitutes that could affect monitoring uptake. Predictors are drawn from the baseline household survey, the implementation questionnaire,[#] and precipitation records, all calculated at the community level. The output of the elastic net approach is the identification of the most influential predictors of uptake.

Second, we perform a content analysis of 34 semistructured interviews conducted after the experiment concluded. These took place in five treated communities within one municipality stratified by treatment status and baseline water insecurity.[‖] For each interview, we hand-coded four indicators for mention of 1) physical barriers, 2) substitutes, 3) monitor costs, and 4) community conflict. We qualitatively compare these indicators to the results of the elastic net.

Results

Both the elastic net and the interview content analysis reinforce the theoretical framework of costs, benefits, and substitutes that may condition uptake of groundwater monitoring. Fig. 2 depicts the top six most influential predictors of uptake according to the elastic net approach.[**] Each bar is color-coded according to the categories of costs, benefits, and substitutes.[††] The x axis scales the level of influence such that the most influential predictor receives a score of 100, and other predictors show their level of influence relative to that predictor.

Coordination costs among community leadership and members comprise the two most influential predictors. Uptake is more likely in communities where the CA meets regularly and where the CA is consistently led by one person or family. The physical barriers proxy is the third most influential predictor. Uptake is more likely where wells were openable at baseline.[‡‡] The monitor costs proxy is the fourth most influential predictor, which captures whether the monitor (i.e., operator or Water Committee) was designated to manage the pump prior to the intervention. Uptake is more likely where the monitor was already visiting the pump, therefore decreasing monitor costs due to our intervention.

A resource benefits proxy related to variability of precipitation is the fifth most influential predictor, suggesting that communities with more variable resource environments are more likely to engage in monitoring. Finally, a substitutes proxy capturing the availability of water sources is the sixth most influential predictor, which suggests that having alternatives for the CPR decreases the likelihood of monitoring.

The content analysis of the interview transcripts aligns with the evidence provided by the elastic net. As Table 1 shows, almost all (88%) of the interviewees in treated communities discussed how substitutes can reduce the likelihood of monitoring uptake. Within this category, respondents pointed to other water sources, such as a nearby reservoir or water trucks, or to SISAR (Integrated Rural Sanitation System), an NGO that assists CAs and operators with maintaining water infrastructure and billing household water use (though does not monitor the status of the resource).[§§]

Conflict was the most frequently discussed type of coordination cost in the interviews. In response to a question about how the community will deal with a broken part in the water system, one resident said, "Here, it is. . .a small community, but there is no, how do you say, unity."

In contrast to the elastic net results, only four (12%) of those interviewed in treatment communities mentioned physical barriers. They were all in communities that took up the groundwater monitoring intervention and brought up physical barriers to explain why uptake did not continue over time.

Discussion

This study combines quantitative and qualitative data to understand the low uptake of a groundwater monitoring intervention. We validate a theoretical framework of costs, benefits, and substitutes that may condition uptake of the externally facilitated monitoring intervention. Uptake is more likely in communities facing lower coordination costs (either within the community leadership or across the broader community), lower monitor

[¶]In *SI Appendix* we also consider a continuous measure of uptake, based on the number of months in which a community sent data. Note that neither of these measures of uptake was prespecified.

[#]After each workshop, facilitators filled out a questionnaire about the workshop and their experience.

[‖]There were 62 interviews in nine communities total: three in T1, two in T2, two in C, two not in project. See *SI Appendix*.

[**]Results were consistent across alternative imputation approaches and when Jpredicting continuous uptake instead of binary uptake. See *SI Appendix* for these robustness checks and the influence rankings of the full set of 30 predictors.

[††]These indicators were not specifically developed to capture the costs, benefits, and substitutes associated with groundwater monitoring and are therefore imperfect proxies.

[‡‡]Wells could be opened in 25 of 80 treatment communities. All communities were trained to and able to monitor electricity use associated with groundwater pumping.

[§§]The elastic net approach did not identify SISAR—present in nearly half of treated communities—as an influential predictor of uptake. It likely reduces coordination and monitor costs while also serving as a substitute. See *SI Appendix*.

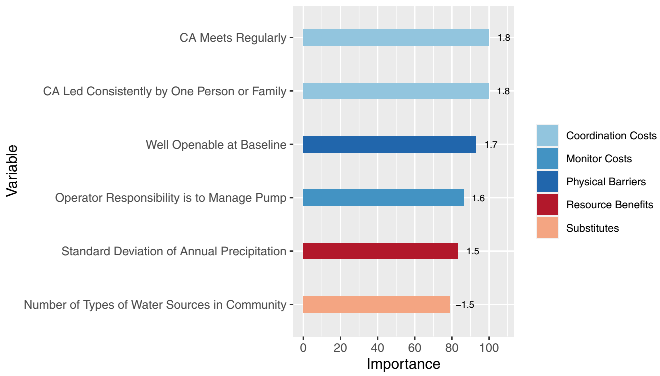

Fig. 2. Top six most influential predictors of monitoring uptake. Models are elastic net logistic regression with cross-validation. The outcome is a binary uptake variable, coded as 0 in communities that did not send any WhatsApp messages and as 1 in communities that did. Predictor variables are listed in the rows in order of predictive influence, with the sign and size of the predictor's standardized coefficient at the optimal learned λ (a model tuning parameter) to the right of each bar. "CA" in the variable names stands for "community association."

costs, and fewer physical barriers. Uptake is also more likely in communities with high variability of precipitation, indicating higher potential benefits of monitoring the resource. In contrast, when there are substitutes for groundwater or external support for infrastructure maintenance, uptake of groundwater monitoring is lower. As this analysis of uptake was not prespecified, and as the indicators we employ are imperfect proxies for the costs, benefits, and substitutes associated with groundwater monitoring, these results should be viewed as indicative, not definitive. However, they are representative of different ways to operationalize CPR theory and reflect the opportunities and challenges that monitoring interventions face in the field.

Our exploratory research represents a promising step toward anticipating heterogeneity in the uptake of CPR monitoring interventions. There are few examples of successful externally facilitated community groundwater monitoring programs. Existing examples rely on multiple stakeholders and many years of engagement (12), which may not be feasible when resources are constrained or implementing institutions have limited capacity. Our exploratory research indicates that the uptake of monitoring interventions surrounding groundwater management is highly sensitive to the costs, benefits, and substitutes involved. Similar heterogeneity should be anticipated in other contexts, especially those with smaller budgets or timeframes and where the intervention is externally facilitated. For example, our findings imply that there may be instances when support for CPR monitoring needs to be focused initially on improving community coordination or removing physical barriers to monitoring the resource. Attention to these important preconditions in advance of rolling out a monitoring intervention could increase the uptake of the intervention and overall program efficiency.

Table 1. Prevalence of topics in interviews

		Topics mentioned			
Monitoring uptake	*n*	Physical barriers	Substitutes	Monitor costs	Conflict, discord
Yes	20	4 (20%)	18 (90%)	15 (75%)	12 (60%)
No	14	0 (0%)	12 (86%)	2 (14%)	8 (57%)
Total	34	4 (12%)	30 (88%)	17 (50%)	20 (59%)

A preanalysis plan for this study is filed on the Open Science Framework (OSF) website at https://osf.io/b2mjc. Washington State University is the Institutional Review Board (IRB) of record, and Columbia University (Protocol ID: AAAR3407) and Princeton University (IRB no. 12412) provide coverage for the Brazilian nonaffiliates. All of these universities granted the project exempt status. The University of North Carolina at Chapel Hill ceded ethical oversight for the project to the other institutions. Additional details regarding the research context, sampling, experiment design and execution, elastic net approach, and semistructured interviews can be found in the preanalysis plan and *SI Appendix*.

Data Availability. Anonymized data files and replication code have been deposited in OSF (https://osf.io/wscxp/) (13).

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