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Risk Management in a Developing Country Context: Improving Decisions About Point-of-Use Water Treatment Among the Rural Poor in Africa

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More than 1 billion people, the vast majority of which live in the developing world, lack basic access to clean water for domestic use. For this reason, finding and promoting effective and sustainable solutions for the provision of reliable clean water in developing nations has become a focus of several public health and international development efforts. Even though several means of providing centrally located sources of clean water in developing communities exist, the severity and widespread nature of the water problem has led most development agencies and sanitation experts to strongly advocate the use of point-of-use treatment systems alongside whatever source of water people regularly use. In doing so, however, development practitioners have been careful to point out that any interventions or infrastructure regarding water safety and human health must also adhere to one of the central principles of international development: to facilitate more democratic and participatory models of decision making and governance. To this end, the research reported here focused on the development of a deliberative risk management framework for involving affected stakeholders in decisions about POU water treatment systems. This research, which was grounded in previous studies of structured decision making, took place in two rural villages in the East African nation of Tanzania.

KEY WORDS: Africa; international development; structured decision making; water

1. INTRODUCTION

More than 1 billion people—or one out of every eight worldwide—lack basic access to clean water for domestic use, with the vast majority of these people living in the developing world. In the East African nation of Tanzania, for example, extreme water shortages are the norm for much of the rural population living in the interior of the country. Despite the presence some of the world's largest lakes (e.g., Lake Victoria and Lake Tanganyika), this region of Sub-Saharan Africa receives an average annual rainfall of less than 800 mm. As a result, people in this area—most of them living in extreme poverty—typically obtain whatever water they can from transient sources. These include seasonal ponds and streams, and in some extreme cases, puddles.

Making matters worse, much of the water that is available for domestic use in this region of Tanzania is contaminated with an array of viruses, bacteria, and protozoa. Associated with these agents are water-borne diseases, including cholera, typhoid, shigellosis, and a range of other diarrheal

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illnesses. Seventeen percent of under-five mortality in Tanzania can be attributed to diarrheal diseases. From a global perspective, more than 5,000 people die from diarrheal diseases linked to contaminated water *daily*, with the highest fatality rate again observed among children under the age of five. To wit, diarrhea kills more children than AIDS, malaria, and measles combined[1,2] and is responsible for more deaths worldwide than all forms of violence, including war.[3]

In addition to the unacceptably high mortality rate, the lack of readily accessible clean water also comes at a significant cost to the fledgling economies and social structures of developing countries. These costs have been linked mainly to the incidence of water-related illnesses, as sick people cannot contribute effectively to economic and social growth, and the large amounts of time that people must spend looking for and hauling clean water over long distances. In sum, water-associated diseases affect poor people in developing countries in a disproportionate way with extreme poverty linked to ill-health, and ill-health leading to further impoverishment.[4,5]

For these reasons, finding and promoting effective and sustainable solutions for the provision of reliable clean water in developing nations has become a focus of several public health and international development efforts. One of the most effective ways to ensure that people have access to clean water is to provide a reliable source of safe water near communities;[6] this can be achieved by constructing a combination of conveniently located wells, water tanks, and tapped pipes near populated areas. But, as any development practitioner knows only too well, this is far easier to state as an abstract goal than to achieve in the context of specific developing communities with limited resources and the need to respect cultural traditions and local customs, not to mention what are often significant political and institutional barriers.

Moreover, even if this infrastructure can be provided, there is still no guarantee that people in developing communities will consume clean water. Recontamination of water between the point of collection and the point of use is widespread;[7] for example, containers that people often use to transport water from a storage tank or centrally located tap to their homes are often contaminated themselves, thereby negating the benefits of an uncontaminated source. Similarly, the homes that compose many rural villages are spread out over vast distances making it difficult for everyone to have easy access to a centrally located clean water source. As a result, many people still end up collecting water from whatever source, contaminated or not, that is closest to them. For this reason, development agencies and sanitation experts strongly advocate the use of point-of-use (POU) treatment systems alongside whatever source of water people regularly use.[1]

POU water treatment systems—which rely upon physical, chemical, or biological processes—have been shown to effectively reduce the incidence of many water-borne diseases.[8,9] But despite the efficacy of these approaches, adoption rates of POU systems remain low in many parts of the world. The reasons for this are manifold. On the one hand, many people simply do not know that the water they routinely use is contaminated. On the other, there is widespread uncertainty about the treatment methods that are available and how to properly use them. There are also significant shortcomings in terms of the reliability of distribution networks to reach communities with reliable and effective water treatment systems (which only serves to heighten the risks faced by many). And, importantly, the POU systems that are made available often do not adequately address the full range of users' objectives and concerns. For example, several POU systems meet health-related objectives but do not address potential users' preferences for other aspects of water treatment such as convenience, odor, and taste.[10,11]

We view these problems through the lens of the decision sciences.[12–15] From this perspective, many of the challenges encountered in the past with respect to providing people with suitable POU systems (and the required knowledge about their use) stem, in large part, from the absence of a comprehensive framework for involving affected stakeholders in the process of decision making about water treatment. The implementation of such a framework would, therefore, help people to clarify and articulate their risk-specific values and concerns; have a hand in setting technical agendas aimed at characterizing the nature of both the risks they face and the efficacy of the available alternatives; and be involved meaningfully in the evaluation of the costs and benefits of competing risk management alternatives.[16]

To this end, the research reported here focused on the development of a deliberative risk management framework for involving affected stakeholders in decisions about POU water treatment systems. Previous studies of POU devices have focused on identifying the appropriate price that people ought to be charged,[17] the role information in facilitating behavior change,[18] POU adoption rates,[19] and a ranking of systems deemed ready for widespread distribution and adoption.[1] However, very few studies have undertaken an up-front and systematic analysis of stakeholders' values and objectives about POU water treatment, and what these mean in terms of people's preferences across competing options.

The starting point for this research was our previous work on structured decision making (SDM). The general goal of a SDM approach is to place the values and concerns of the potentially affected individuals squarely in front of policymakers so that they lend maximum insight to decisions that will be made about risk management options. A typical SDM approach engages people in the following steps:[13,15] defining and clarifying the context for the impending decision; characterizing what matters to decision-makers and stakeholders in the form of clearly articulated objectives; identifying and establishing the projected consequences of alternatives that address these objectives; and directly confronting the value tradeoffs that arise when objectives and alternatives conflict.

SDM has been used extensively in a variety of mostly Western risk management contexts.[20–23] However, very few cases have focused on risk management in developing countries. The reasons for this are understandable. In rural areas, participants often have to travel great distances—often on foot—in order to take part in SDM efforts, and have very limited time that they can devote to multiparty initiatives.

From the standpoint of SDM facilitators, other obstacles exist. Among them, there is general lack of facilities where people can interact with increasingly common computer-based decision support tools; in the case we outline below, even something as simple as a flip chart was impossible to come by. At the same time, political, cultural, and language barriers between facilitators, policymakers, and local participants can further hobble the best intentions of researchers and practitioners.

Despite these challenges, however, many of the risk management problems faced by communities in developing countries are ideally suited to the application of SDM. People are faced with many complex and pressing problems that require thoughtful solutions. Similarly, there is pressure from aid and donor agencies to obtain input about alternatives from multiple stakeholders, and to confront the tradeoffs that arise as a result of conflicting objectives. With this as background, we report the results from research aimed at developing and testing a SDM-based framework for rapid deployment in an international development context.

The objectives of this work were twofold: from an applied perspective, we sought to help people identify a POU water treatment system (or suite of systems) that was both effective with the primary water sources in the study areas and stood the best chance of seeing daily use in rural households. From a methodological perspective, we also sought to evaluate the appropriateness and effectiveness of SDM approaches set in a developing country context.

2. METHODS

2.1. Context: POU Water Treatment

This research unfolded under the auspices of the Center for the Advanced Study of International Development at Michigan State University, which is overseeing a multiyear and private-donor-funded development effort in Tanzania. An important element of this effort is addressing health risks by ensuring that people would have sustainable access to clean water at the household level. According to our research partners in Tanzania, fewer than 10% of households in rural Tanzania disinfect their water prior to using it for drinking or cooking.

In consultation with our in-country partners and several recognized experts in the areas of international development, sanitation, and microbiology, we identified five alternative POU systems thought to have the highest efficacy rates with the primary water sources in our study areas. In selecting these systems, we relied heavily on results from published studies, documentation from the manufactures of different POU systems, and expert judgments—all of which led us to believe that each of the chosen systems would adequately disinfect water from the primary sources at both of our study areas. (However, because levels of water contamination tend to vary greatly in rural Tanzania, a POU system that may be effective with one water source may not be effective with another. For this reason, an important component of our research was to conduct field tests of water quality before and after the use of each POU system at our two study sites; see Section 2.4.) In addition to efficacy, we also selected POU systems that were both widely available and technically feasible (in that they did not require electricity or batteries to operate[4]) in Tanzania.

The first of these systems was boiling, which relies on prolonged exposure to heat to neutralize bacteria, viruses, and parasites. Unlike the situation in much of the developed world, boiling is not an easy or straightforward process among the rural poor in Tanzania. It requires first collecting firewood or charcoal (which may be made or purchased). This process alone can take an individual, usually a woman in the household, several hours. After next building and then maintaining a fire, which also may require hours, a family can obtain approximately 4 L of boiled water in 30–60 minutes. (The few families that possess a kerosene stove can cut this time to approximately 20 minutes.) According to our contacts in Tanzania, it could take as many as six hours to obtain 4 L of disinfected water by boiling, including the time it takes to collect the wood, build the fire, and boil the water.

The second method, termed solar water disinfection (SODIS), involves first placing collected water (with a turbidity of less than 30 NTU[5]) in a clean, transparent 1–3 L PET water bottle. Next, the capped bottles are placed in full sunlight for 10 consecutive hours. On days with >50% cloud cover, it is recommended that bottles be left outside for two consecutive days. This method is not effective during periods of rain. Using SODIS, bacteria, viruses, and parasites are neutralized by UV-A radiation present in sunlight. After the requisite time, it is recommended that water be consumed directly from the bottles. When empty, the bottles must be cleaned with soap prior to reuse and excessively scratched or cloudy bottles should be replaced.

Method three involves using a 1% sodium hypochlorite solution (dilute bleach branded locally as WaterGuard), which at this concentration is effective at neutralizing bacteria and most viruses. (However, it is not effective at inactivating certain protozoa such as *cryptosporidium*.) To use WaterGuard, a user simply adds one standard capful (approximately 8 mL) of the WaterGuard solution to 20 L of water. WaterGuard may also be used with turbid water; however, two capfuls of the solution must be used in this case. The water must then be stirred for approximately 5 minutes and allowed to rest for 30 minutes before it is consumed.

Similar to WaterGuard, the fourth (and newest in Tanzania) method involves using a disinfectant branded as the PUR® sachet by its manufacturer, Procter & Gamble. Like WaterGuard, this method also relies upon a time-release hypochlorite—$Ca(ClO)_2$ in this case—to deactivate microbes. The PUR® sachet also contains a flocculant, ferric sulfate, which acts to remove suspended materials (through settling) from water. The effect is of the flocculant is quite dramatic as it quickly renders the most turbid water clear. About the size of a sugar packet from a café, each sachet treats 10 L of water. However, unlike WaterGuard, using the PUR® sachet is more time and labor intensive. The user adds the powder from the PUR® sachet to 10 L of water in a mixing bucket and stirs for 5 minutes so that it may fully dissolve. Next, 5 additional minutes are allowed for the flocculating agent to act in the suspended solids. The water is then transferred to a second vessel while filtering it through a tightly woven cloth. Finally, 20 additional minutes are required prior to the water being ready for consumption.

The fifth and final method involves using a large clay filter (approximately 40 cm in both diameter and depth), which rests inside a larger collection receptacle fitted with a spigot. The clay filter, manufactured in Tanzania, is made primarily of terracotta that has been coated with antimicrobial colloidal silver. Water is poured into the filter by the user and, at a rate off approximately 2 L/hour, moves through the small pores in the terracotta and into the collection receptacle. Filtered water can then be served via the spigot on the collection receptacle. Water can be continuously added to the filter so that there is always a supply of approximately 10 L in the collection receptacle. If properly cared for, each clay filter has a usable lifespan of five years.

2.2. Study Locations and Participants

Our research was conducted near two small rural villages in Tanzania: Milola and Naitolia.

Milola, which is located in the Lindi region of southeastern Tanzania, represents one of the poorest areas in the country. Approximately 10,000 people live in Milola split across four subvillages (termed

[4]Though electronic devices utilizing solar battery chargers (e.g., mobile phones with solar panels affixed to the back of the device for charging the internal battery) are gaining prominence throughout Tanzania—including the small hamlets and villages inhabited primarily by the rural poor—a reliable solar-powered POU water treatment system is not yet widely available in the country.

[5]Nephelometric turbidity units; water that has a turbidity of >30 NTU must first be filtered prior to use with the SODIS method.

Milola-A, Milola-B, Milola C, and Milola D by the Lindi District Office) and a series of smaller hamlets. Our work concentrated on a small hamlet with a few hundred[6] inhabitants, which was located nearest to Milola A. The primary source of water for domestic use in this area is a centrally located tap to which water is piped in from a nearby natural spring (known locally as the Chipwapwa). Alternatively, local residents may also collect water from a secondary source, a near by river (known locally as the Ninu River).

Naitolia is located in the Monduli District of north-central Tanzania. This village consists of 245 households and a total population of approximately 1,300 spread out over several square kilometers. As in Milola, we worked with residents of a small hamlet located near the center of Naitolia, which is comprised mainly of members from the Maasai ethnic group (the Maasai make up the majority of the population in Naitolia). The primary source of water in Naitolia is a well and adjacent water storage tank located approximately 8 km from the village center (which consists of nothing more than a small administrative office and meeting space). At the time of this research, a secondary water source was a small, transient pond approximately 2 km from the village center where the water had been designated for domestic use only.

2.3. Structured Decision Making

A typical SDM process for POU water treatment in North America or Europe might take several days; this would include time for several deliberative elements, including: (i) defining the decision context, including key stakeholders and constraints; (ii) several rounds of eliciting objectives (including appropriate attributes and measures; i.e., measurement criteria) from key stakeholders and decisionmakers; (iii) tests of water samples obtained from each POU system by both stakeholders and experts to determine how well each performs across each of the stated objectives; and (iv) formal trade-off analysis aimed at informing either a rank order of options or a decision to implement a single alternative. In Tanzania, however, we were faced with the constraint (imposed by the local district offices at each study site) that we would only have 3.5 hours to conduct each individual SDM workshop. As a result, a third objective of our research focused on the development of an SDM approach that could be implemented in a developing country context—with all of the additional challenges that this kind of work introduces—under significant time pressure.

All three of the workshops at a given site (Milola and Naitolia) were conducted over two consecutive days. On day one at each site, we conducted two workshops with the two groups of five women only (one in the morning and one in the afternoon). On day two, we worked in the morning with five members of the village water committees. The afternoon was reserved for a discussion of the workshop results with the village water committees. There was a primary focus on women because women are responsible for gathering and using household water. Village Water Committee members were also emphasized due to their more in-depth knowledge of the local water supply and system (in comparison to other villagers).

To make efficient use of our limited time, each workshop followed the same basic protocol. Each began with a 30-minute introductory section, where we introduced ourselves as well as the members of our team (our research assistant and two paid translators from the National University in Dar es Salaam); we also asked that participants introduce themselves at this time. Following these introductions, we provided a description of the nature of our work and our objectives for the workshop. We also obtained informed consent from each participant. Next, we provided an overview of the health risks associated with untreated water, as well as the expected health benefits of using POU water treatment devices. This aspect of the introductory session was prepared in advance and was developed with insights from experts in human health (a registered nurse from Michigan State University who accompanied us to Tanzania) and microbiology (based at Michigan State University and the Centers for Disease Control and Prevention in Atlanta, GA, USA). Finally, we introduced workshop participants to the concept of SDM. To make the concept of SDM salient for them, we used an example—decisions about daily activities—to guide our discussion. Participants were encouraged to ask questions at any time during the introductory section, and at all times during the remainder of the workshop.

Immediately following the introductions, the focus of the workshops turned to eliciting objectives about water for domestic use and POU water treatment. This process took approximately 45 minutes.

[6] We were unable to obtain an accurate estimate of the population for either study area from either the Lindi (Milola) or Monduli (Naitolia) district offices.

Because of the need to be efficient, and because of the low levels of education among the workshop participants, we used boiling (with which all participants were familiar) as a reference point in the discussion of objectives. Time was taken during this phase of the workshop so that each participant could articulate their objectives and concerns, and to separate means from ends objectives. As part of this session, time was also taken to identify locally relevant measurement criteria associated with each objective. Workshop participants set their own measurement criteria for each objective with the exception of one: safe water (see Section 2.4).

During the discussion of objectives, the methodology in Milola and Naitolia differed slightly. In Milola, many workshop participants had never worked with outside researchers or development practitioners before. As a result, the nature of this stage of the workshop—where people were encouraged to talk about what was important to them in contrast to what might be important to outside researchers and practitioners—was quite foreign to them. To make this part of the workshop easier, fun, and more intuitive, we asked participants in Milola to first draw pictures on sketchpads that characterized their objectives and concerns about water and water treatment; these were then discussed by the group. We also used pictures to characterize objectives in Milola because many of the participants could not read; as a result pictorial symbols understood by the group were use to characterize objectives during the discussion periods and on the consequence matrix (see below). In Naitolia, by contrast, participants were more accustomed to working with outside researchers on a variety of health and social issues (e.g., agricultural development, primary education, and emergency medical interventions). As a result, a more straightforward discussion of objectives and measurement criteria took place.

Following the discussion of objectives, the workshops moved into 60-minute interactive demonstrations of each of the POU methods outlined above. First, each of the five POU methods was demonstrated by the authors; accompanying the demonstration of each method was an explanation—with answers and discussion when participants raised questions—of how each POU system worked to disinfect water; in the case of the PUR® sachet, we also took time to explain the mechanism by which the flocculant, ferric sulfate, worked to improve the clarity of treated water. The goal here was to help participants better understand each of the systems and their associated benefits. This demonstration and discussion was followed immediately by an interactive session where participants tested each of the POU methods themselves.[7] This part of the workshop was designed to be quite lively, with open discussion among the facilitators, participants, and translators. During this interactive session, workshop participants were encouraged to add to, or revise, their initial list of objectives and associated measurement criteria (given that this part of the workshop provided additional context about each of the POU options before them).

Fig. 1. The evaluation of water samples by workshop participants in Naitolia.

After the conclusion of the interactive session, workshop participants blindly evaluated post-treatment samples (see Section 2.4) from each of the available POU systems in terms of their ability to meet their stated objectives (Fig. 1). Each sample was scored on a constructed scale [24] of 0–5, with participants placing the desired number of tokens in cups (Milola) or showing by a corresponding number of fingers (Naitolia). When the scoring of samples across all of the objectives was completed, the results across all of the participants were summarized in a consequence matrix. This process lasted for approximately 30 minutes.

We then undertook a 45-minute discussion of tradeoffs across the different POU systems. Because we worried that an advanced discussion of

[7] Because time was limited, the demonstration of boiling was undertaken using a portable kerosene stove. However, the demonstration was discussed in terms of the prominent local context, which involves boiling over a fire.

tradeoffs using approaches like even swaps[13] or swing weighting[25] would have been too complex[8] and time consuming, we instead employed a lexicographic decision rule based on attribute ranks beginning with alternatives that exhibited practical dominance. Participants discussed the available POU systems on an attribute-by-attribute basis until the participants settled on a preferred option.

We were discouraged from using recording devices—audio or video—during the workshops for fear that they would be intimidating or distracting to participants. Instead, our research assistant working with one of our translators took meticulous notes at all times during the workshop. These notes, as well as all of the materials gathered from participants at the close of the workshop (e.g., sketches and the consequence matrix), were cross-referenced with the notes of the two facilitators and the second translator after the completion of each workshop.

2.4. Water Quality

A key element of our research was ensuring that the POU systems that people in Milola and Naitolia would choose among were effective in terms of disinfecting water from commonly used sources. However, as was the case with our workshops, our time in the field was extremely limited so thorough testing of samples shipped to a European or U.S.-based lab was not an option.[9] For this reason, we elected to use IDEXX Colilert-18 microbiology testing kits (IDEXX Laboratories, Westbrook, ME, USA) for water samples collected at source in Milola and Naitolia. These kits are effective for detecting both *E. coli* and coliforms and, importantly, conform to the U.S. EPA's rule regarding standard methods for the examination of water and wastewater.

We collected water from both the primary and secondary sources in both Milola and Naitolia in the morning of the day prior the start of the SDM workshops. Enough untreated water from each source was drawn for pretreatment testing. The remaining water was divided and treated using each of the available POU systems. Treated water from the primary source was then used in the SDM workshops when participants evaluated the posttreatment samples (see Section 2.3). However, enough treated water obtained from each system and source at both study sites was retained for analysis with the IDEXX Colilert-18 kits. As part of the water testing process, pre- and posttreatment samples—in replicates of three—were appropriately incubated with a field incubation unit and assayed prior to and following treatment with each POU device. Appropriate positive and negative controls were assayed using the same method.

[8]Our previous experience in North America suggests that people often need a lengthy description of these methods, as well as time to practice them, prior to use in a specific decision context.

[9]More thorough testing of water samples, to include assays for protozoa and viruses, will be the subject of future work in the area.

3. RESULTS

3.1. Milola

Because the Village Water Committee is responsible for decisions about community-wide implementation of POU treatment methods, we report only the final recommendations made by this group. It is noteworthy, however, that participants in this workshop evaluated a consequence matrix that included aggregated results from all three workshops conducted in Milola. Also of note, only four of the five POU methods (boiling, WaterGuard, PUR® sachets, and SODIS) were evaluated in Milola because, despite repeated attempts over four weeks leading up to the workshops, we could not get the manufacturers of the clay filters to deliver them to the village.

Participants across the three workshops in Milola focused their discussion on a total of eight objectives for POU water treatment methods and the water that they could obtain from them (Fig. 2). Objectives related to the POU methods themselves included ease of use, the price it would cost to purchase the necessary materials, the amount of time required to disinfect the water, and the amount (volume) of water that could be disinfected at a time. Objectives related to the water obtained from each of the POU methods included color (i.e., clarity), health and safety (i.e., the efficacy of the POU method), odor (i.e., not smoky, fetid, or smelling of "medicine," which is how participants characterized the smell of chlorine), and taste (i.e., not smoky or tasting of "medicine"). We discussed with participants the option of collapsing color, odor, and taste (which are each means objectives) into a single ends objective, which a small number of participants referred to as the "enjoyment" derived from drinking water. However, we elected to keep these objectives separate because the majority of participants felt that the ability to address tradeoffs across objectives deemed most important—namely, taste and odor—was important in terms of

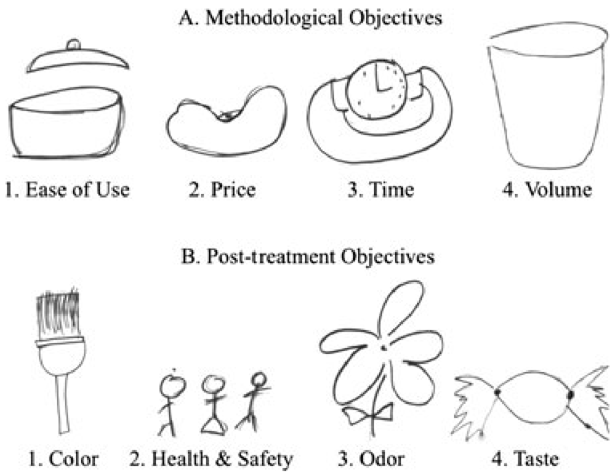

Fig. 2. Examples of sketches by workshop participants depicting objectives for both POU methods ("methodological objectives") and the water derived from them ("posttreatment objectives"). The sketches are self-explanatory, except perhaps for the following: The sketch for "ease of use" is a pot with a lid because participants wished the ease and simplicity of putting clean water into a pot or cup and using it. The sketch for "price" is a cashew nut, which many people in Milola harvest and sell at market. The sketch for "health and safety" depicts a family. The sketch for "taste" is a wrapped piece of candy.

being able to more fully evaluate the different POU methods.

After further discussion, workshop participants elected to focus their evaluation of the POU methods on five objectives: taste, odor, ease of use, the amount of time required to disinfect the water, and health and safety (i.e., efficacy). The amount of water that could be treated at a time was excluded because participants felt that a quick and easy method would allow them to disinfect more than enough water in a reasonable period of time. The clarity of the water was excluded because participants felt that this could be easily dealt with, regardless of the POU method used, simply by first filtering the untreated water through a piece of fabric. The cost of each POU system was also excluded in this analysis because the agreement between the donor-funded development initiative (see Section 2.1) and the district office was the POU method that was ultimately selected by participants would be provided at little or no cost to individual households. It is important to note that, if no such agreement regarding subsidies for POU water treatment were in place, it would have been critical that cost be included in the analysis of tradeoffs outlined below. Decisions about which objectives to exclude were made prior to the evaluation of the POU methods to minimize bias.

Table I depicts participants' ratings, and the resulting rankings, for each POU method on a 0–5 scale (where 0 = lowest rating and 5 = highest rating on a given attribute). Because SODIS was shown to be ineffective in terms of disinfecting water from both sources (the primary tap and the secondary river),[10] we prevented participants from providing evaluations of taste or smell (the latter out of concern that water may accidentally be ingested). Moreover, SODIS performed poorly in terms of both the time required to disinfect water (ranking fourth) and ease of use (ranking third). As a result, workshop participants removed SODIS from further consideration.

Though boiling was effective at disinfecting water from both sources, yielded water with the most positive odor (ranking first), and was deemed easy to use (ranking first again), participants balked at both the amount of time required to disinfect water and the "smoky" taste (which both ranked third). We gently pressed this issue to help ensure that participants were not dismissing an otherwise effective POU method; when we discussed this issue, participants pointed out that very few people in Milola took the time to boil their water prior to drinking or cooking with it and pointed to themselves as examples of this trend.

This left only WaterGuard and the PUR® sachet for further consideration. Of these two remaining options, only the PUR® sachet was effective when used with water from both the tap and the river. Participants agreed that the differences between the methods were negligible in terms of taste, odor, and time. However, participants felt strongly that WaterGuard was the easier of the two methods because of its one-step simplicity. The final tradeoff, then, was one between efficacy and ease. This quality of PUR, coupled with overall concerns about its novelty, led participants to conclude that WaterGuard was the preferred option despite the fact that it was only effective with water from the communal tap (from the river, only *E. coli* was neutralized by WaterGuard).

[10]The failure of SODIS to disinfect water in our study has been the topic of much discussion within (and outside of) our research team. The effectiveness of SODIS, in terms of its ability to disinfect water, has been the subject of several studies (26, 27). In the absence of (a) further testing and (b) more time in the field, we can only conclude that, due to local weather conditions, our samples should have been exposed to daylight for a longer than recommended period of time.

Table I. Consequence Matrix Depicting Participants' Mean Ratings and Rankings of POU Methods in Milola; Ratings Were Provided on a 0–5 Scale, Where 0 = the Worst Possible Performance and 5 = Best Possible Performance on a Given Attribute; The "Efficacy" Attribute Shows the Results from the Pre- and Posttreatment Assays for the Presence (+) or Absence (−) of Both *E. coli* and Coliforms

	Boiling		Water Guard		PUR® Sachet		SODIS	
	$\bar{x}_{Rate}$	Rank	$\bar{x}_{Rate}$	Rank	$\bar{x}_{Rate}$	Rank	$\bar{x}_{Rate}$	Rank
Taste	3.9	3	4.6	1	4.4	2	—	—
Odor	4.7	1	4.4	2	4.3	3	—	—
Time	3.3	3	4.2	1	4.0	2	2.6	4
Ease of use	4.4	1	3.8	2	1.6	4	2.6	3
Efficacy	Tap	River	Tap	River	Tap	River	Tap	River
Pretreatment	+	+	+	+	+	+	+	+
Posttreatment	−	−	−	+	−	−	+	+

Thus, the final recommendation by the Village Water Committee, which was unanimously accepted by members of the previous two workshops, was for the adoption of WaterGuard coupled with the implementation of a village-wide risk communication effort urging people to boil water for domestic use obtained directly from the river.

3.2. Naitolia

The process followed in Naitolia was nearly identical to the one followed in Milola. Once again, the village water committee in Naitolia is responsible for decisions about POU treatment methods; thus, we report only the final recommendations made by this group. However, as was the case in Milola, participants in this workshop evaluated a consequence matrix that included aggregated results from all three workshops.

As was the case in Milola, we could not effectively treat water from either source (the primary tank and secondary pond) using SODIS; i.e., *E. coli* and coliforms were found in all posttreatment samples using this method. As a result, SODIS was once again dropped from our analysis in Naitolia. However, we were able to obtain the clay filters (by picking them up ourselves from the manufacturer in the nearby city of Arusha) and brought these to Naitolia for evaluation by workshop participants.

Participants across the three workshops in Naitolia discussed a total of seven objectives for POU water treatment methods. Objectives related to the POU methods themselves included ease of use (which, in Naitolia, encompassed both the time required to treat water and the operation of the method itself), the volume of water that could be treated per unit time (i.e., the amount of water that could be treated with a single application of the method), and participants' judgments about the risks associated with using each method (which was a qualitative attribute that differed by method, see below). For volume and risk, participants elected to rely on qualitative evaluations of either "low" or "high," rather than 0–5 rankings. Objectives related to the water obtained from each of the POU methods included taste, color, odor, and health and safety (i.e., the efficacy of the POU method). Unlike the case in Milola, participants in Naitolia wished to evaluate the POU methods using all seven objectives.

Ceramic filters performed poorly across most of these objectives, yielding treated water that performed the poorest in terms of taste, color, and odor (Table II). Similarly, participants felt that the filters performed poorly in both terms of the volume of water that could be treated over time and the perceived health risks associated with this method. On this latter point, participants were concerned that some people, mainly children or men in a hurry, would simply scoop drinking water out of the top of the unit, where untreated water had yet to pass through the ceramic filtration stage (rather than using the relatively slow flowing spigot located at the bottom of the receptacle). So, despite the fact that the filters were effective in terms of both ease of use (which ranked first because all one needs to do is poor water from a source into the top of the unit) and effectiveness (in that the filters completely disinfected water from both sources), it was removed from further consideration at the request of the workshop participants.

Boiling was also effective in terms of completely disinfecting water from both sources. And, unlike Milola, participants in Naitolia were generally pleased with both the taste and odor of treated

Table II. Consequence Matrix Depicting Participants' Mean Ratings and Rankings of POU Methods in Naitolia; Ratings Were Provided on a 0–5 Scale, Where 0 = the Worst Possible Performance and 5 = Best Possible Performance on a Given Attribute; The "Efficacy" Attribute Shows the Results from the Pre- and Posttreatment Assays for the Presence (+) or Absence (−) of Both *E. coli* and Coliforms

	Boiling		Water Guard		PUR® Sachet		Ceramic Filter	
	$\bar{x}$ Rate	*Rank*	$\bar{x}$ Rate	Rank	$\bar{x}$ Rate	Rank	$\bar{x}$ Rate	Rank
Taste	4.7	1	3.9	2	3.6	3	3.1	4
Color	4.2	2	4.1	3	4.5	1	4	4
Odor	4.6	1	4.0	2	3.8	3	3	4
Ease of use	1.2	4	1.6	2	1.4	3	1.7	1
Volume·time^{-1}	Low	2	High	1	High	1	Low	2
Perceived risk	Low	1	Low	1	High	2	High	2
Efficacy	Tank	Pond	Tank	Pond	Tank	Pond	Tank	Pond
Pretreatment	+	+	+	+	+	+	+	+
Posttreatment	−	−	−	+	−	−	−	−

water (both ranked first). The risks associated with boiling were judged to be negligible because all participants were accustomed to working with fire. However, boiling performed poorly in terms of both the volume of water that could be treated (i.e., one small pot at a time) and ease of use. On this latter point, participants pointed to the hours required to collect firewood and water, and the added time of bringing water to a boil. As a result, boiling was also dropped from further consideration.

As was the case in Milola, this left only WaterGuard and the PUR® sachet. Again, of these two POU methods, only the PUR® sachet was 100% effective with water from both the tank and the pond. However, participants stated that treated water derived from the use of WaterGuard tasted and smelled better. In addition, WaterGuard had low perceived risk (due mainly to widespread familiarity with this method in Naitolia), was judged to be easier to use, and could treat a large amount of water in a single, short session. In terms of the PUR® sachet, participants were leery of the method by which it rendered even the most turbid water clear (PUR® sachets were ranked first in terms of water clarity). Some participants expressed the concern that the PUR® sachet seemed almost "supernatural," referring specifically to the flocculating properties of the ferric sulfate and its ability to render the most turbid water clear. One memorable participant, in particular, expressed fear that consuming water treated with the PUR® sachet might have the same result inside the body, stripping away an individual's internal organs. Despite our assurances to the contrary, the high perceived risk associated with the PUR® sachet effectively removed it from further consideration at this time.

As a result, there was consensus among representatives of the Village Water Committee that WaterGuard should be adopted as the POU method of choice. We pointed out that WaterGuard was not effective, according to our tests, at treating water obtained from the pond; only coliforms were neutralized while *E. coli* remained. Nevertheless, the judgment of the committee was to select WaterGuard and recommend that development funds be used to pipe water from the holding tank to tap that would be built closer to the village center. In addition, the committee recommended a village-wide risk communication effort warning people of the need to boil water obtained from the pond.

4. DISCUSSION

The first of the overarching objectives that guided our research was to help people identify a water treatment system (or suite of systems) that was consistent with their objectives and, therefore, stood the best chance of seeing daily use in rural households while also ensuring that the water systems that participants selected proved effective with the primary water supply. At both of our study sites, Milola and Naitolia, the application of the SDM process led participants to select WaterGuard as the method of choice. Our tests (Tables I and II) showed that this method was indeed effective in terms of treating water obtained from the primary source in both areas. However, WaterGuard was not shown to be effective with water obtained from the more heavily contaminated secondary sources at both sites (i.e., the river near Milola or the pond in near Naitolia).

As a result, we grappled with our own decision as analysts working as part of an international development effort to recommend to private donors a POU method that was not completely effective with all of the local water sources. In the end, however, we elected to side with the participants in our Tanzanian workshops for three main reasons. First, WaterGuard was shown to be effective with the primary, permanent, and most heavily used water source at both sites. It was pointed out to us by sanitation experts that, even if WaterGuard was effective with the secondary water source near Milola and Naitolia, there were no guarantees that it would be effective with other water sources that may be used by some community members in Milola or Naitolia. Similarly, many secondary water sources—near Milola, Naitolia, and elsewhere—are transient meaning that water quality from a given source may change drastically from place to place and from season to season. As a result, ensuring that the most frequently used source of water for domestic use could be effectively treated was deemed to be a satisfactory result in terms of providing assistance to communities that only rarely benefited from disinfected water.

Second, our job as facilitators of an applied process was aimed at helping local participants to identify a POU method that was consistent with their own objectives and the associated tradeoffs that were most appropriate to them (vs. the objectives and related tradeoffs as might be determined by outside researchers or development practitioners). The fact that participants could also point to their own experiences—e.g., the low adoption rate for boiling water despite their acknowledgment that they should more regularly use this method—as justification for not selecting a method that was completely effective with all water sources served to further ease our minds.

And third, workshop participants left us with the strongest impression that WaterGuard stood the best chance of being used by people in both villages on a sustained basis. As we note above, very few people in Milola and Naitolia undertake POU water treatment *of any kind* despite the fact that all of the POU methods that were the focus of this research are available in Tanzania. As a result, a recommendation that leads to the adoption of a POU method that is (a) effective with the primary water sources in the two study areas and (b) likely to be used on a regular basis is an important step forward. This finding stood in contrast to the expectations of many of our research partners when we started our work that the PUR® sachet would be the preferred method in Milola and Naitolia.

We stress, however, that the recommendation to adopt WaterGuard should not be viewed as set in stone. In both Milola and Naitolia, the decision by participants to recommend WaterGuard was driven in large part by concerns about the risks associated with alternative POU methods, namely, ceramic filters and the PUR® sachet. (It is important to note that the PUR® sachet has been approved by the U.S. Environmental Protection Agency and is deemed safe to use by the Centers for Disease Control and Prevention.) Based on our observations, the reluctance to adopt the PUR® sachet was based on a general lack of familiarity with—and, as a result, trust in—this particular method. Concerns about risks aside, however, workshop participants were nearly unanimous in their agreement that the PUR® sachet addressed a majority of their objectives associated with ease of use and produced water of very high quality. It is our view, therefore, that an opportunity exists to slowly familiarize communities with the PUR® sachet as a means of building trust in, and future support for, this method.

For example, alongside making WaterGuard widely available, it is our view that community exposure to PUR® sachets should also be increased; this may be achieved through a variety of means, including risk communications that focus upon this particular POU method, offering samples to individuals and families who would like to test the method, and facilitated demonstrations of how it may be used (including a discussion of how the various elements of the method—particularly the flocculant, ferric sulfate—work). Indeed, these strategies could be implemented with a focus on both PUR® sachets and WaterGuard as part of an adaptive management[(28,29)] framework aimed at providing additional insights to potential users about the pros and cons of both methods.

The second of the overarching objectives that guided our research focused on evaluating both the appropriateness and effectiveness of SDM approaches set in a developing country context. Put another way, we used our research as an opportunity to identify "lessons learned" about the application of SDM in developing communities with an eye toward future applications in Africa and elsewhere.

Though the amount of time available to conduct each workshop was short—3.5 hours—our goal in conducting this research was to follow as closely as possible the same basic SDM framework that has been the focus of other risk management initiatives;(23,30,31) this included time devoted to defining the decision problem that was the focus of the SDM effort, eliciting and clarifying objectives, discussing measurement criteria, evaluating alternatives, and confronting the tradeoffs that choosing among the alternatives entailed. Nevertheless, severe time pressure, the remoteness of the study locations, and technical limitations (in terms of both SDM and, in the case of the context for our research, water treatment) stood out as challenges that ought to be addressed in subsequent research initiatives of this type.

For example, the short time under which each workshop unfolded meant that there was little opportunity to more fully explore—and refine—both participants' objectives regarding water treatment and the associated performance measures used to operationalize them in the context of POU systems. While the objectives we identified were similar to those observed in other studies,(7,8,19) the overall quality of the SDM approach would have benefited from more time to discuss alternative ways of accounting for (in particular) qualitative attributes such as taste, odor, and clarity.

Related, this research did not account for the cost of alternative POU systems as either an objective or attribute in the final analysis of options. This was due in part to extreme poverty in our study areas (participants had very little money that could be devoted to water treatment when considering other expenses) and constraints imposed by the sponsors (in that POU systems, as well as the cost of any new required infrastructure, would be subsidized—at least for the foreseeable future). However, had cost been included—which we believe would be necessary in future studies of end users' preferences for POU systems—it is likely that participants' preferences for the different POU systems would have changed. Specifically, discussions with our in-country partners and some workshop participants suggest that longer lasting POU systems—i.e., those that need only be purchased once—such as ceramic filters and SODIS—may rise in participants' rankings over systems such as WaterGuard and the PUR® sachet, which need to be purchased or replenished on a more regular basis.

Regarding the POU systems themselves, the remoteness of our study areas, coupled with the short amount of time we could spend in the field, meant that we (and the workshop participants) could not get an accurate sense of the effectiveness of certain methods. For example, microbiological studies of SODIS suggest that the method is, in fact, effective at removing pathogens from water in the field.(26,27) More time at each of our study sites would have allowed us an opportunity to more fully evaluate the effectiveness of SODIS in terms of its water treatment capabilities and, importantly, from the standpoint of the objectives related to taste, odor, and clarity outlined by participants. Similarly, ceramic filters were not delivered to Milola, which meant that workshop participants could not evaluate this approach. Ideally, participants at both study sites would have evaluated all five of the POU methods that are available in the area (though the inability of the manufacturer to deliver ceramic filters to Milola raises questions about their availability in certain parts of Tanzania).

Technical limitations in the field also proved to be challenging, particularly in the context of evaluating tradeoffs. As we note above, we employed a lexicographic decision rule based on participants' ranks of each POU system on an attribute-by-attribute basis. A more comprehensive and integrated approach would have been to use either even swaps,(32) which would have required more time and arithmetic skills on the part of participants, or swing weighting,(25) which would have required the use of a computer. While even swaps would likely have been very difficult to employ in the field (likely to the point of being unworkable), swing weighting does warrant further consideration in future studies so long participants can be made comfortable with the use of a computer, and sufficient time is available to explain and demonstrate the approach.[11]

Despite these challenges, however, we were impressed by how effective the time-compressed SDM model turned out to be and, as a result, are optimistic about its applicability in a developing country context. This was, in large measure, a result of both the high level of sophistication displayed by the participants in all of our workshops and the common sense appeal of SDM. When we arrived in Dar es Salaam, we were cautioned by the Tanzania-based research coordinator assigned to our research team that working with people in Milola and Naitolia would be akin to "working with children." Similarly, several colleagues forewarned us that we would encounter a

[11] One of our subsequent field studies with villagers in Central America—Arvai and Kellon, in prep.—relied upon the use of laptops loaded with custom decision support software (which included a swing weighting module) to evaluate alternative land management strategies.

largely passive group of participants who were more likely to tell us what they thought we wanted to hear, rather than what really mattered most to them. Neither of these warnings turned out to be true. Even though the levels of literacy and education among participants was low, the levels of refinement and polish on display in all of our workshops was remarkably high; in point of fact, we would characterize it as being on par with what we have experienced when working in North America and Europe. With minimal prompting from us, workshop participants in both Milola and Naitolia were able to articulate in vivid detail their views as they related to each step in the SDM approach (e.g., about objectives, measurement criteria, tradeoffs, etc.). Moreover, all of the SDM workshops were incredibly lively, with participants openly discussing their thoughts and feelings and, at times, challenging one another (and us as facilitators) on the basis for certain claims and arguments (e.g., the health risks associated with using the PUR® sachet).

Critical in terms of ensuring that our workshops would unfold in this way was the interactive nature of the SDM workshops. In the weeks prior to our arrival in Tanzania, we discussed the need to contextualize both the POU water treatment and decision support initiatives for workshop participants so that they could contribute effectively and, importantly, make their values clear to our project leaders. The analogy we drew upon in this regard was a combination of a Western structured decision-making process and Julia Child's *The French Chef*. On the one hand, we wanted to be faithful to the required decision support elements identified in previous SDM efforts and then implement these in a workshop setting. On the other, we wanted to give participants the opportunity to observe and interact with each of the POU methods in real time to the point of being able to see—and taste and smell—each method in action.

Indeed, the interactive nature of the SDM workshops was, in our view, essential in terms of providing people with the necessary context for our discussion of objectives and, later, the exploration of tradeoffs. For example, the ability to interact with each of the POU water treatment methods allowed participants to reflect upon objectives that, otherwise, may have been difficult to contextualize. Illustrative of this point were the objectives and measurement criteria related to *time*, which is typically not conceptualized by looking at a clock; instead, time is judged relative to other activities (e.g., allowing water to boil for the amount of time it takes to collect an additional armful of wood for a fire). Another example relates to participants being able to see each of the methods in action; e.g., concerns about the PUR® sachet would likely not have come to light if participants could not observe in real time the effect of ferric sulfate on a turbid water sample. And, clearly, being able to relate their observations to objectives—while having this information fresh in their minds—helped during the discussion of tradeoffs when comparing the different POU methods.

These results are also promising from a community development standpoint, where decades of work by researchers and practitioners have focused on improving quality of life for people living in impoverished regions of the world. Much of this work has encompassed projects that hold as core objectives the need to facilitate more democratic and participatory models of decision making and governance, while also enhancing human health through the provision of sustainable infrastructure. Along these lines, several participants noted during the workshops that our work in both Milola and Naitolia represented the first time that Western researchers had taken the time to discuss with them in detail *their* objectives and concerns, and how these could inform *their* preferences, in *any* community development context. It was reported to us—with some sadness and bewilderment—that the norm is for researchers to visit, speak briefly with village elders or high-ranking officials from the district office, and then return with recommendations that to many people seem disconnected from local realities. It is precisely this kind of result that SDM is designed to avoid.

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