

# Evidence-based decision-making on water quality in domestic water supply in Malawi, Ecuador, and Brazil

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## Abstract

Scholars and practitioners advocate evidence-based decision-making (EBDM) because facts lead to beneficial outcomes. At the same time, EBDM to reduce risks in water quality is under-studied. We examine types of decision-making by water utilities and government agencies, and the nature and origin of evidence available to them in their work on delivering safe drinking water to households. Using qualitative content analysis, we comparatively analyze water utilities and government agencies in Malawi, Ecuador, and Brazil. The results show that the water utilities perform combinations of decision-making types on water quality such as implementation, intelligence-gathering, and evaluation and choice, while government agencies perform more intelligence gathering. Sources and types of information are mainly water consumers, guidelines for water quality standards, and self-monitoring from water utilities. The analysis is useful in establishing a foundation for developing evidence-based management within water supply services, and potentially other water resources management activities.

*Keywords:* Brazil; Ecuador; Evidence-based decision-making; Governance; Malawi; Water supply

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## Introduction

The failure to deliver safe water to households is a global challenge rooted in ineffective decisions regarding ageing infrastructure, water scarcity, affordability, accessibility, and governance of water

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resources. Decision-making is an ambiguous relationship between commitment and action – an artificial construct – and that commitment does not necessarily come before action (Langley et al., 1995: 266). Decision-making may be improved by drawing from relevant evidence. Evidence, or rigorously sought facts that inform a decision, is an old idea that became prominent in the early 20th century as a result of the emergence of social sciences such as public policy, economics, and sociology (Head, 2010: 81–82). For example, scholars and practitioners advocate evidence-based decision-making (EBDM) to support public policy (Kay, 2011; Argyrous, 2012), public health (Brownson et al., 2013; Jacobs et al., 2014), and environmental policy (Eaton, 2013; Kirchhoff et al., 2013; Werner et al., 2015).

The study has two purposes: first, to examine types of decisions water utility personnel routinely make regarding the delivery of safe water; and second, to examine the sources of information and types of information related to such decisions. We focus on the experiences of Malawi, Ecuador, and Brazil because they provide a unique cross-section of water management practices in diverse socioeconomic contexts. The decision process examined water quality management, such as monitoring, testing, and delivering safe water to households.

Few EBDM studies refer to water supply governance with the exception of Wiek & Larson (2012), Kurian & McCarney (2010), and Huntjens et al. (2012). The results of our study build on Wiek & Larson's work that focuses on what people do with water and why (Wiek & Larson, 2012: 3160–62), by showing a comparative field example of how local-level and national-level information flows toward acts of decision-making. Kurian & McCarney (2010: 14–15) stress the importance of reliable information on economically vulnerable communities beyond head-counting, and to include nuanced information such as measures of concentrations, inequalities, and distributions of poverty among other factors. In relation to this call for accountability via information-based decision-making and nuanced information, our results support these views. For example, we examined a specific topic of decisions: that of water quality decisions in utilities, and the kinds of decision that this involves and the linked information (source and nature). While our study did not explicitly focus on accountability, it was implicit in our aim for effective decision-making.

Evidence drawn from information can be unclear,

*'We don't always know what information is available, and even if we do, we can't always access it. If we can access it, we cannot always make use of it, perhaps because it is in the wrong language or the wrong format, or otherwise not suited to our needs' (Parker, 2000).*

For example, a study on information, knowledge, and water governance in Ghana found that information available was not consistently transformed into knowledge; and that knowledge was not the major determinant for decision-making (Schiffer et al., 2008: 11). Lessons from research on rural water supplies and water quality advise that '... coordinating actions around a functionally-useful target such as production of an annual sector status report would encourage information sharing, coordination and information for decision-making and may be embedded in legislation' (Bartram, 1996: 127).

It is useful to note distinctions of the forms of evidence: data, information, knowledge, and evidence (Davenport & Prusak, 2000: 2). *Data* means structured records of transactions, a description of an event without the context or purpose of the event. For example, a record of 30 m<sup>3</sup> of rainfall per year in a city describes available water but, without context or purpose, it is unclear whether this amount is sufficient for agriculture or households. *Information* is 'data that makes a difference' and is meant to impact the receiver and shape how they perceive something. The receiver of information decides whether the

message is indeed useful for making a decision. In developing our study, we follow Parker (2000: 235) in that the user of information must be central in our analysis and action,

*‘... ultimately it is up to the user to decide whether or not to use the information, and if so, how ... our first concern should be to find out why users decide to use, or not to use, information, and in what way’.*

In comparison, *knowledge* is derived from information. Davenport & Prusak (2000) explain, ‘Knowledge is a fluid mix of framed experiences, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information.’ Our study focuses on information because it directly relates to decision-making in that the user of the information chooses to use it and how to use it, and will use information and evidence interchangeably.

We focus on *how decisions are made* in relation to information, instead of what decision-makers do (Nutt, 2011). For example, to achieve the first goal of the study, which is to identify the types of decision-making in water supply systems, we used themes such as intelligence-gathering, formulation, implementation, and evaluation and choice, in line with our conceptualization of decision-making as an action-taking process (Nutt, 2011: 9) (Figure 1). To address the second purpose of the study, the source of information, we analyze decisions with four dimensions: (1) the organizational space where the action takes place: *type of organization*; (2) the topic of the decision: *content of decision*; (3) the origin of the information: *source of information*; and (4) the outcome or next step after the decision was taken: *action/interpretation* (Table 1).

## Methods

### Country case selection

For consistency in this comparative case study, water quality management processes were analyzed. Therefore, all decision processes have some relationship to water quality monitoring, testing, and delivery.

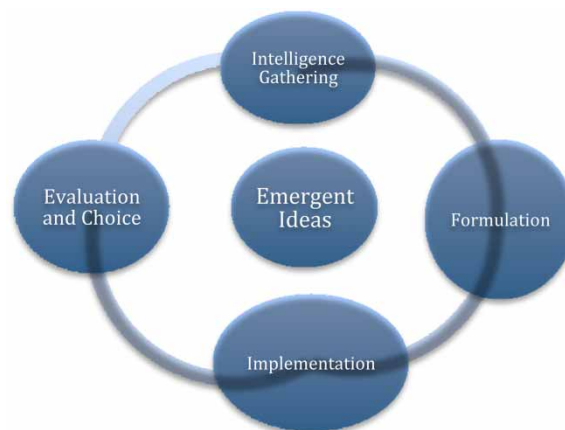


Fig. 1. Action-taking processes in decision-making. Source: adapted from Nutt (2011).

Table 1. Dimensions of the decision-making process.

Dimension	Example
Type of organization	Water provider or government agency
Content of decision	Delivery of safe water to households
Source of information	WHO water quality standards
Action/interpretation	Deciding to stop water service temporarily if standards are not met

Most decisions on water quality management involved numerous characteristics of decision processes that in the real world overlap with each other and are not linear. However, for the purpose of this article, they will be discussed in distinct terms. Malawi, Ecuador, and Brazil were selected from a country-clustering model approach that organized countries into five clusters based on similarities and differences across nine water and sanitation indicators: GDP per capita; official development assistance; Gini-index; governance effectiveness; expected years of education per capita; renewable fresh water per capita; % urban; improved water source; and improved sanitation source (see Onda et al., 2014: 381) for a more detailed description). The result is a comparative country typology that provides an alternative to selecting country cases based on geographic or income-based indicators, commonly used in case selection. Each cluster is representative of similar water and sanitation access and demographic factors that affect water and sanitation performance and progress. One of the strengths of the clustering approach is that each country in a cluster is characteristic of the cluster in terms of water quality management characteristics. That is, water quality management scenarios in Brazil may provide clues for examining what is working or challenging in other countries in its cluster – keeping in mind that contextualization is also needed.

The characteristics of each cluster are as follows (after Onda et al., 2014). *Cluster number 1* has 33 countries and the *highest access* to safe water and sanitation, a very high (but not 100%) rate of water and sanitation access, and the lowest (sometimes no) amount of water and sanitation overseas development assistance of the groups that receive aid. Example countries include Australia, Japan, and the USA. *Cluster number 2* has 15 countries, including **Brazil**, Argentina, Iran and Russia, *high access* to safe water and sanitation, and is characterized by the second-highest GDP per capita, second-highest governance effectiveness scores, and second-highest expected years of education. *Cluster number 3* has 28 countries, including Costa Rica, Turkey, and Vietnam, and *medium access* to safe water and sanitation. *Cluster number 4* has 24 countries, including **Ecuador**, China, and India, *low access* to safe water and sanitation and is characterized by similar GDP per capita, expected years of education, urbanization, water and sanitation access, and more renewable freshwater resources than countries in Cluster number 3. *Cluster number 5* has 51 countries, including **Malawi**, Morocco, and Pakistan, the *lowest access* to safe water and sanitation, and is characterized by the lowest GDP per capita, governance effectiveness scores, expected years of education, urbanization, and water and sanitation of all the clusters. Cluster number 5 countries have higher overseas development assistance and renewable freshwater resources compared with the other clusters. We chose to focus on three countries, one from three of the five clusters, due to limited resources. Within each cluster we selected a country that provided the researchers access to water management networks for examining decision-making and information dynamics. The selected clusters, 4, 5, and 2, provided a cross-section of the lowest-two and second-highest countries ranking on water and sanitation indicators. While we focus on three out of five clusters, such a cross-section still provides sufficient comparative analysis between distinct clusters with little overlap between them.

Water for domestic consumption in Malawi is provided to households, kiosks, and other piped water systems by five regional water boards that serve the rural regions and major cities: Northern, Central, Southern, Lilongwe (capital city), and Blantyre (largest city by population and financial center). The study focuses on four of the five water supply organizations, referred to as Rural Water Provider No. 1 and No. 2, and Urban Water Provider No. 1 and No. 2. The Ministry of Irrigation and Water Development is the primary government agency that implements policies set by the Malawi Parliament. No independent water regulator exists, and each water provider monitors its own water quality. The Ministry of Public Health once had jurisdiction to monitor water quality but has since transferred this function to the Ministry of Irrigation and Water Development, possibly related to changes in thematic focus and a lack of resources.

Water providers in Ecuador are mainly public (municipalities manage urban supply, and community drinking water committees (CWCs) manage rural supply), and there are two private companies, in two major cities, Guayaquil and Cuenca. The Ministry of Urban and Housing Development (MIDUVI) is responsible for providing technical assistance to the CWCs. The Ministry of Health (MOH) is responsible for surveillance of water quality (Article 96). There are water guidelines for water quality surveillance for the MOH, but there is no law to enforce these guidelines and limited resources for the MOH to do all of the testing.

In Brazil, public state companies serve most municipalities as licensed concessionaires, the result of an effort to improve the services and benefit from economy of scale in the 1970s (PLANASA). In the last two decades, there has been an effort to promote different forms of private participation in the market (service/management contracts, leases, concessions and divestures), so far with mixed results.

### *Selection of key informants*

We selected key informants in each country in a non-probability sampling technique where existing study subjects recruit future acquaintances (commonly known as a snowball sample) according to how closely they worked with water quality issues in their organization. The selection of key informants was based on their work on the following scales: national, state/provincial levels, and city/town levels, and included individuals from water systems (utilities and small systems) and government agencies. In this study, we interviewed a cross-section of operational governance and management levels within each country and across each organization. Interviewing everyone in the organization was not realistic. [Table 2](#) summarizes the types and number of organizations interviewed for the study. The water systems that provided water to households were selected according to their coverage of a municipality or rural community regardless of their status as publicly or privately owned or managed. While the nature of an organization can influence motivations for decision-making, we did not focus on this greater public vs

Table 2. Number of interviews and organizational type: Malawi, Ecuador, and Brazil.

Country	Water service providers	Government	Total # of individual interviews
Brazil	5	6	11
Ecuador	15	11	26
Malawi	13	4	17
<b>Total</b>			<b>54</b>

private tension in water supply because connecting to this broader debate was beyond the scope of the study. The focus of the study is an in-depth analysis of how evidence is used in decisions when delivering safe water. A variety of personnel from public water systems (Malawi and Ecuador) and some privately managed water systems (Brazil) were interviewed.

### *Semi-structured in-depth interviews*

After the research participants were identified, their perspectives were systematically collected for later analysis. We conducted semi-structured interviews (after [Denzin & Lincoln, 2011](#): 48) in the dominant languages of the three countries – Malawi (English), Ecuador (Spanish), and Brazil (Portuguese) – which allowed for direct perspectives from interview participants, providing higher likelihood of accuracy and understanding of nuanced meaning. We prepared and translated the interviews from the original languages to English when necessary. We audio recorded the interviews to preserve accuracy; however, several interview participants (in the cases of Brazil and Malawi) did not want to be recorded, and therefore notes were used to document these interviews. In addition to the audio recording, we kept a mixture of hand notes and electronically recorded notes.

Our data-gathering process and sources involved semi-structured interviews of water governance practitioners in government and service provision in Malawi, Ecuador, and Brazil at four administrative levels: national, city/town, organizational, and individual. Semi-structured interviews were a mixture of informal conversation and standardized open-ended interviews, appropriate for this case study because they increased the relevance of research questions and remained conversational and situational so as to encourage candid responses from participants. The interviews ranged from 20 minutes to one working day. Semi-structured interviews were carried out once for each interview participant and each of the country case studies was visited for two to three weeks by one of three researchers. The interview narratives were triangulated with peer-reviewed and gray literature to provide more than one perspective on answers to the interviews.

### *Qualitative data analysis*

The majority of interviews were transcribed by the authors of this paper, again providing another opportunity for a close reading and familiarization with the perspectives of the research participants. We iteratively analyzed the data for thematic patterns and relationships. Qualitative content analysis of interview transcriptions (after [Pettigrew, 1985](#); [Langley, 1999](#)) was used to examine themes such as type of organization, content of decision, source of information, and action/interpretation as discussed above in conceptual underpinnings. These categories were later compared with concepts of action-taking processes such as intelligence-gathering, formulation, implementation, evaluation and choice. Each of the researchers who visited the three countries functioned as key informants for the three case studies, searching for examples, patterns, and relationships among the roles of actors, their decision-making content, goals, and outcomes. Using QSR International's NVivo qualitative data analysis software (version 10) and hand notes, we organized the comparative case study by country and organizational type, according to the issue of the decision action. NVivo Software somewhat mimics analysis of written (audio and visual) notes, by organizing documents, allowing for highlighting of quotes by research participants, assigning themes to parts of texts, and retrieving them, as well as visualization of patterns, among other functions. NVivo can aid in the organization of qualitative analysis,

but does not take the place of the researcher, in the same way that Microsoft Word can aid in the writing and editing of documents, but does not replace the writer. Three phases of iterative inquiry and writing framed the process of analysis, starting with exploring which data were actually available, what detail on relevant thematic areas could be focused upon, and then making the story coherent, and accurate. After isolating decision actions in each country, several themes emerged, which are discussed in the results section.

Our interdisciplinary perspective provided a comprehensive approach to the analysis of EBDM from the perspectives of organizational and institutional processes, water quality management, and technology and knowledge management. Utilizing these diverse, but related, perspectives allowed us to examine the problem of how information is used in decision-making from three different angles, and triangulate frames of thought and various sources. Together, we refined the research questions, designed the interview guide, and analyzed the data from three disciplinary perspectives. Particularly innovative was that three of the authors individually visited one case-study country – Malawi, Brazil, and Ecuador – gathering data using the integrated interview questions of the other two researchers. This approach provided multiple perspectives with which to examine the research question, and saved time and resources with regard to conducting a multiple-country study. Reinforcing the triangulation of the interdisciplinary methodology was our piloting the interview questions together as a team in three water utilities around the state of North Carolina in the USA. The pilot was critical to uniformly conduct data collection. The University of North Carolina Institutional Review board reviewed this study and approved the protocol on 28 September 2011.

## Results

### *Malawi*

*Water utilities.* In Malawi, an example of a decision related to water quality by *Rural Water Provider No. 1* was on whether to allow consumers to break pipes to access water because services were disrupted when electricity for pumping water to sections of the town was not working. Water customers were the source of information on broken pipes to the water utility through their actions of phoning an emergency number to report water leaks. The purpose of the decision from the utility was to determine whether to stop customers from breaking pipes for drinking water access during hot summer months. Speed was necessary in this decision by the utility manager, limiting time for reflection and further information-gathering from customers or senior-level managers for consent. Ethical and health concerns overrode any formal procedures of arresting ‘water thieves’. The water utility manager weighed the health, ethical, and political risks in his decision-making process. The rural location of such a provider may increase the likelihood of immediate amnesty for pipe breakers due to reputational risks within a small population.

*Rural Water Provider No. 2* provided an example of decisions related to chlorine monitoring. If the chlorine tests do not meet guidelines, “... we cannot distribute that water, we would have to stop the plant and fix the problem”. Information that is important in such a decision comes from the chemist [that works for the water provider]. If the chemist says the chlorine levels are below standard, we must stop distribution.

*‘Detailed tests are done by the chemist ... here, for the whole [Rural Water Provider No. 2] ... like bacteriological, chemical, but then this other test like the chlorine which is very useful ... we are*

*given the standards ... WHO standards and the Malawi Bureau of Standards ... WHO is a standard ... and the Malawi ones are more specific.'*

One of the challenges of delivering safe water to communities is vandalism when the pipes are broken for 'free' water and faults are not reported immediately.

*Urban Water Provider No. 2* in Malawi must frequently decide how to balance efficient use of water from the water source at minimal costs to energy, personnel time, and use of disinfection chemicals. This is related to the efficient transfer of water from sub-stations to main stations so that no area of service is without water. One example of a decision regarding transferring water from one region of the city to another region involved conditions where demand for water was greater than available supply. The infrastructure is older and energy for pumping is a challenge in Malawi. Energy consumption of an hour equals approximately 10,000 m<sup>3</sup> of treated water, a weakness of operations over which the utility has no control. A second example is of a decision involving political pressure:

*'If a government official is residing in a particular part of the service area, the utility must make sure water is available. If the government official moves to another part of the city for meetings or residence, the utility must ensure water is available – it is a priority.'*

Timing and politics were important influences on the urban utilities' decisions on water governance. Appropriate billing of customers is an additional example of decision processes and sources of information needed to make decisions:

*'[If] ... we are not properly billing our customers and they are not paying [on] time, [we would examine the problem] to see what ... is happening ... and then [determine] where we want to go ... what is it that we need? Do we need another [computer] server? Whether the solution we want to put into place is used elsewhere. Then can we go learn how it is done. That would be the information gathering before we even decide which solution we would put in place'* (Urban Water Provider No. 1, Information Technology Manager).

*Government agencies.* The Ministry of Irrigation and Water Development is tasked with monitoring water quality; however, they are not able to monitor sufficiently due to lack of resources. To monitor water quality, supplies and equipment are needed. Occasionally UNICEF has provided such supplies; however, the Malawian Government has not consistently procured such supplies. Planning and budgeting are decentralized; therefore, some districts give importance to monitoring water quality, while other districts do not. The Ministry of Public Health has an obligation for testing household samples, but does not do so adequately because it does not have its own testing facilities to cross-check with the water utilities that are self-testing and monitoring their water quality. With regard to information-sharing within the Ministry of Public Health, email is not commonly used for communication because it is unreliable. Paper memos, phone calls, meetings and workshops are more common.

The Ministry of Irrigation and Water Development interprets the direction and policies handed down by the Malawian Parliament and, where necessary, provides technical feedback. Recommendations for policy issues may also originate with the ministry, submitted to the Parliament for their review, to be adopted or rejected. The Ministry of Irrigation and Water Development consists of the principal



secretary, under-secretary, and four technical departments: water supply, water resources, sanitation-hygiene, and irrigation. In addition to the technical departments are the divisions of administration and support, human resources, planning, and finance. One of the major programs in the Ministry of Irrigation and Water Development is the National Development Program intended to harmonize efforts and funding in the water and sanitation sector throughout Malawi. Donors financing this program include the World Bank, European Union, European Investment Bank, African Development Bank, AusAid, and DFID, among others. The components include urban/town/rural water, sanitation and hygiene, water resources, and program management and reform (see [World Bank \(2013\)](#) for further details).

The water sector in Malawi has fragmented databases; therefore, there is a need for harmonizing such databases and indicators. Information for such databases that assist with implementing the National Development Program originates from district councils and water monitoring assistants of which there are very few. As a result, health service officers may also be a source of information. After the front-line officers collect the data, it is given to regional water officers, then submitted to the departments of water services. Lastly, this data is relayed to the planning department database. The Ministry of Irrigation and Water Development intends to develop the data-collection tools for the regional districts as a guide, with simple software, such as Microsoft Excel, to capture issues related to sanitation and water quality. According to an interview with a staff member in the Ministry of Water Development and Irrigation, the Malawi water sector

*‘... does not have a harmonized sector wide information management system ... [however] decisions in the water sector are being guided by the Annual Sector Performance Review Report that is presented at a Joint Sector Review from which evidence based decisions are made but still the process is affected by lack of proper information’* (Interview, Staff Member, Ministry of Water Development and Irrigation).

### *Ecuador*

*Water utilities.* In Ecuador, rural CWCs manage funds and hire a water operator to manage the water quality treatment, maintenance of the distribution system, and any water quality testing. The CWCs suggested that it is difficult to create a culture of payment for the water service among customers so that the financial resources are available for operation and maintenance of the water system. A private company that runs water treatment and water quality testing in a major city in Ecuador is considered to be a successful model for these activities; therefore, it shares management strategies and is visited by urban and rural CWCs and urban municipal water managers from around the country to learn from its practices.

*Government agencies.* On the national level, decision-making on water quality surveillance includes decisions in the MOH about where to run the tests, and how often; however, water quality surveillance is constrained by limited financial and personnel resources. Decision-making at the level of the water system is characterized by monitoring of water quality throughout the system, and where and when those tests are taken. MIDUVI builds capacity within all of the municipalities so that they are testing water quality and reporting those results back to the government. Limited financial resources and technical capacity, however, prevent routine monitoring and surveillance in many water systems. ‘Currently,

we know there is a deficit in the area of water quality testing. There is no capacity in taking water quality tests, we are trying to build capacity, and in the laboratories' (MIDUVI, Ecuador). At the same time, awareness of these problems exists:

*'We would like to have the equipment and the resources to test the concentration of pesticides in the water, and the equipment to take residual chlorine tests in all of the water systems, but we do not have the resources. In the northeast, there is oil contamination of the drinking water, but water testing is too expensive to do tests ... The test for pesticides (a large problem here), is also too expensive. The cost is approximately \$150 per pesticide test'* (MOH, Environmental Health Division, Quito, Ecuador).

Water quality surveillance is also the responsibility of the health technicians who work for the MOH in rural areas. The MOH has a sampling plan, but they have limited resources to get from one place to another (MOH, Quito, Ecuador). There are not sufficient vehicles available and the health technicians have other responsibilities, and do not have the time for adequate surveillance of water quality (MOH, Quito, Loja and Esmeraldas, Ecuador). This results in insufficient surveillance. Usually the water systems that are closer to the health center are tested but more-remote systems are rarely tested (MOH, Quito, Ecuador). In urban areas, the municipality or a private company is responsible for water quality testing. Typically, there is a protocol for guiding water treatment and monitoring. In addition, CWCs in rural areas are elected every two years, which triggers discontinuity in personnel and institutional knowledge when working to build capacity within the CWC. If the newly elected CWC is friendly with the formerly elected CWC, the older CWC might assist with training the newly elected CWC, but this does not always occur (Ministry of Health, Environmental Health Division, Quito, Ecuador).

While lack of sufficient funds and training for water quality management in Ecuador exists, the practice of identifying and using information in decision processes is apparent: 'When we make decisions about where to have a water system in a particular community, we first identify the community need, detect the demand of the community, and then identify a source' (Technical Engineer, MIDUVI, Ecuador). The lack of information, such as continuous and regular surveillance by government officials, results in insufficient evidence for decision-making about water quality.

### *Brazil*

The constitution in Brazil requires federal, state and local levels to be responsible for promoting sanitation services, but municipalities are ultimately responsible for implementing and maintaining water and sanitation services for the population. These services can be contracted out to concessionaires, but that does not take away the responsibility from the municipalities for the quality of the service, although this responsibility is often neglected. The main problem for financial stability of water utilities is that infrastructure is not directly financed by tariffs or municipal taxes, but is dependent on the federal government for funding (Mayor, western region; Manager, state utility). In 2007–2010, an overhaul of the national directive for water and sanitation and subsequent regulations have updated and clarified ownership and responsibility issues, and there is an effort for more-consistent financing of infrastructure.

*'Brazil has advanced greatly in terms of legislation in the last 20 years, but it has yet to have the desired impact on the ground ... A great challenge is the lack of strategic planning and coordination at the regional and local levels'* (Advisor, State Water Resources Management Agency).

*Water utilities.* An example from Brazil regarding the decision on which municipality they first serve or invest in, in the case of a large, state-controlled utility, relates to political pressure: ‘If we think only in terms of technical and financial viability, many municipalities would not be served. So the decision is political, it comes from the top.’ Sometimes popular pressure from communities also plays a role. As an example, a community in the semi-arid region, with no water sources within 40 km, is served by the State Controlled Utility because no other utility would do so:

*‘We do serve this municipality, but the water comes from a deep well that was originally perforated by an international company in search of oil. The pump broke and there is no technology here to fix it. The company who manufactures the pump wanted a prohibited [sic] price for a new one. So we ended up having to do an ‘unorthodox’ fix through another company, in order to be able to get it back to work’* (State Controlled Utility).

That highlights a difference between decisions from the private or government sectors. The private sector would not choose to invest in, or to serve, such a community. The State Company, although not ultimately responsible to serve that community (the municipality is), chose to do so because of the political pressure on the State Government, but also because of a sense of duty to serve all communities in the state.

An additional challenge in Brazil is that older distribution systems may not be properly mapped. Retired workers and senior residents sometimes help to identify the location of the pipes. In many cases of leakage and water quality problems, the population brings information to the utilities. Brazil has a telephone hotline for general information collection and dissemination for approximately 30 public services, such as dialing 115 for water and sewage, 151 for consumer protection, and 150 for the health and sanitation agency. Such phone numbers work anywhere in the country, will connect the caller to the local utility and can be used for reporting problems, soliciting services and connections, or reporting illegal connections and dumping. Most utilities have an online version of these services. Ombudsmen are also available, especially at state companies.

*Government agencies.* The large geographical space for coordinating information systems in Brazil’s water supply management is a challenge. In Brazil, the decision to develop a Water Supply Atlas

*‘... was based on the desire to have comparable data for planning. Before that, the states would report their data as they saw fit. So the idea for the Water Supply Atlas was to have a comprehensive, yet comparable, overview of the water production systems’* (Federal Agency).

In addition to data management, ‘common sense’ and duty are also characteristics of water quality governance in Brazil. An example from the western region of Brazil, of data management and governance of water quality, is the procedure to shut down distribution if water samples show contamination. In a western-based utility, the water operator, from a private management company that is contracted by the municipality, explained: ‘It’s just what we do, our training requires that.’ When questioned what would happen if the mayor demands the operation to start, ‘We would not. We need to be responsible’, indicating that a political order would not change or influence a technical decision if there was risk to the population.

The federal government recommends guidelines, facilitates capacity-building and provides financing. Federal law has been improved in recent decades and financing is heavily dependent on political influences. Expansion and maintenance are the main decisions for small utilities. State utilities need to manage resources in order to serve their array of customers. Many times, that means investing in one locality instead of another, and the decision is often political. Legal aspects also drive many decisions, ‘In many cases we will not get paid ... but we are, legally, as well as socially, obligated to serve that guy and connect him to the services’ (State Utility Manager, on illegal occupations). This again highlights the contrast between decisions from public and private entities. If a private company does not expect to be paid, it would simply not bid to serve the municipalities with low income. One fear from privatization trends is that once private companies bid in the wealthy communities, the state companies would be left to serve the poor ones, but now without the revenue from the wealthy areas.

At the local level in Brazil, the decision to hire a management company to handle the operations improved the service. The company met the expectations, they worked with what they had, made it more efficient, and employed capable technicians and managers. By fixing leaks, they were able to serve some neighborhoods for longer periods of time, according to the mayor of that municipality. This solution can certainly be a good compromise between privatization and public control. For small municipalities in particular, this can unburden the public administration, but at the same time guarantee that poor areas are still served.

## Discussion and conclusions

We examined the types of decisions made by water utility and government agency personnel, and the nature and origin of evidence available to them in their work of delivering safe drinking water to households in Malawi, Ecuador, and Brazil. The study’s goal was broken down into two parts: first, what kinds of decisions do water utility personnel routinely make regarding the delivery of safe water? Second, what were the sources of information and types of information related to such decisions? In the following, we discuss water utility and government agency behavior in using information in their decisions on water quality risk reduction.

In Malawi, water utilities in rural and urban areas are making implementation-type decisions, for example whether to allow water users to break pipes to access water and how to determine the priority and timing of water transfers (Rural Water Provider No. 2). Relevant information that they used in implementation-type decisions was that water is not adequately reaching households because of infrastructure malfunction; water users need to access drinking water; there are surges in demand for water; and government officials’ need for water is prioritized. As a result of the decision to allow water users to break open pipes for water, water was made available to consumers and a potential public health problem was averted. In relation to prioritizing water delivery in particular areas of the city to serve government officials, particularly the president, the utility is perceived to be facilitating smooth functioning of the government. Additionally, when there is a surge in demand, energy for pumping water is a challenge (Urban Water Provider No. 2). In the case of determining appropriate billing for customers, Urban Water Provider No. 1 performs several action-taking processes such as intelligence-gathering, formulation, evaluation and choice, and eventual implementation, cycling between such points of action. Such highlighted areas may suggest where decision-making actions and information could be identified and enhanced.

In comparison with the Malawi utilities interviewed, water managers in rural and urban Ecuador and government officials made decisions based on intelligence-gathering, evaluation and choice. Decisions on when to test water quality were based on evaluation of available resources (funds and personnel). Decisions by water managers on when to treat drinking water were also based on an evaluation of resources. Once tests were run, the water managers used the data from water quality testing in urban and rural areas to adjust water treatment (levels of chlorine commonly used to treat drinking water) and identify where maintenance might be needed in the distribution system. The government officials who work for the MOH and are responsible for water quality surveillance used the water quality test results to make recommendations to water managers, yet faced the constraints of limited personnel to do the testing and vehicles for transport to rural water systems. The resource constraints faced by municipalities, CWCs, water managers and government officials were often a result of consumer unwillingness to pay for their water bill. While regulations exist mandating payment, in close-knit rural communities shutting off water when customers do not pay was not always possible. Creating a culture of paying for water among consumers was a challenge mentioned by many CWCs in rural areas. For municipalities and CWCs, sources of information used in decision-making are household water bills that show who pays and who does not, chlorine tests that show the levels of chlorine throughout the distribution system, and monitoring of the water system. It was suggested by water managers that customers who do not trust the quality or supply of the water may not be willing to pay for water services. This, in turn, worsens the potential for municipalities and CWCs to accrue sufficient revenue to purchase equipment, to maintain and operate water systems, and to pay operators. Furthermore, even if chlorine tests are available, water service operators must be sufficiently trained to interpret the results.

In Brazil, the utilities in rural and urban areas discussed decision types such as intelligence-gathering, and evaluation and choice. For example, a state-controlled utility in this study stated that breaks and leaks are reported by customers, sourced from water users in an emergency call system and are derived by monitoring the water system. The rural utility discussed an example of evaluation and choice, where utility managers said they would shut down the plants if samples are contaminated, or if they run out of chlorine. Sources for this information about contamination are the utilities' self-testing, although testing is done less frequently than in urban areas, partly because small providers may not have in-house laboratories. Urban utilities self-test, and are required to do so, as well as report results on customers' bills. The context for this for urban utilities is that contamination is difficult to detect in urban areas because of the complexity of the system and because funding for preventive maintenance is more difficult to obtain than funds for expanding the network.

In their interviews, utility personnel discussed decision types such as implementation, evaluation and choice, and intelligence-gathering. The sources and nature of information that fed into the decision situation were water customers, tests, and benchmarks based on regulations. In these areas, all three countries' utilities were similar: routine, though important decisions are taken that would greatly affect the well-being of their households served. Interestingly, the lack of monetary resources was mentioned by research participants, but was not central to the managers' description of decision-making, except in Ecuador. A possible reason for this lack of mention of money or resources in Malawi or Brazil could be that, in the specific decisions discussed, managers do not perceive resources as a central concern, or that low resources are naturally a part of the background.

Ecuador and Brazil did not necessarily have their own laboratories, which affected speed and accuracy of water tests and therefore decisions on whether more or less treatment is needed, and whether to shut down delivery and notify customers. Differences in size and geography affect management

problems and decisions to be made about them. In Brazil, the complexity of infrastructure and urban areas makes information-gathering difficult for robust decisions on water quality. In Malawi, political contexts emerged more than in Ecuador and Brazil. The decision to allow pipes to be broken has humanitarian effects, but also political. The water utility manager in Malawi of Rural Water Provider No. 1 stated that he had to make a swift decision even before he could consult higher-level managers, that the need for water was greater than the need for protocol.

In Malawi, the Public Health Ministry monitors water quality of water utilities, which can be categorized as intelligence-gathering. The Ministry's source of information for water quality is self-testing from water utilities. Water quality is measured based on WHO standards and national standards set by Malawi's statistical office. According to the research participants, the Ministry of Public Health focuses on clinical health more than on water, sanitation, and hygiene, which some participants found to be a challenge for their work on water quality monitoring. Furthermore, the Ministry of Public Health does not have the staff or resources to monitor utilities' self-testing. The Ministry has village-level and district-level outreach programs. Similar to Malawi, Ecuador's Public Health Ministry also conducts intelligence-gathering of water monitoring and in the context of a limited budget, makes decisions on where to run tests, and when to use their limited fleet of vehicles. The Ministry's sources of information for such decisions regarding water surveillance, and when and where to run water quality tests include health officials and presidents of rural water committees. The nature of such information, from health-related government employees and leaders of communities, could potentially be affected by political influences. Monitoring of water quality by the Public Health Ministry is a major challenge.

In Brazil, federal and state agencies, which may not necessarily be health-related, go beyond intelligence-gathering of water quality monitoring, compared with Malawi and Ecuador. The Brazilian agencies stated that they make decisions on guidelines, capacity-building, planning and management, programs and financing. In contrast with Malawi and Ecuador, Brazilian federal agencies stated that they have sufficiently trained technical staff, and support the capacity-building of utilities. Malawi and Ecuador share the similarity that the government agencies that we interviewed claimed to insufficiently monitor water quality because of insufficient resources. Brazil's government agencies are a stark contrast in that, in addition to monitoring, they also set guidelines, while resources were stated to be not a primary challenge.

In conclusion, water utilities perform combinations of decision-making types on water quality such as implementation, intelligence-gathering, and evaluation and choice, while government agencies perform more intelligence-gathering. Sources and types of information are mainly water consumers, regulations and guidelines for water quality standards, and self-monitoring from water utilities. These results are useful in establishing a foundation for developing evidence-based management within water supply services, and potentially other activities such as integrated water resources management, and relationships between water and agriculture, land management, and climate-change adaptation. Such a foundation points us in the direction of knowing the types of decisions to expect, how they might evolve, and how to improve availability, quality and quantity of needed information.

One limitation of our study is that we focused on one specific topic of decisions, that of water quality, which reveals specific behavior and sets of information. Broadening to a variety of decision types beyond water quality may be useful in understanding decision and information flows in water supply to households. At the same time, this focus on water quality provided systematic and in-depth analysis. A second limitation is the timing of the decision processes, which were a one-time event, based on the memory of the research participants. This allowed for self-selection by the participants and their natural

perceptions without external influence, and feasibility for the study. However, this approach relied on the research participants' memory, which could be fallible. Another approach may use a longer observational period by researchers of a decision process that is similar among case studies, so that self-reporting and external observation are combined for improved fact-gathering.

Future research regarding EBDM in water supply governance could include how to identify whether all relevant actors are participating in the decision process and what information or input is needed from them; determining the topic of decision that will aid in narrowing the goal and needed evidence; identifying at which governance level the decision must be taken and its level of influence; and determining the urgency of the decision. Future studies could also add the focus of how water systems that are public, private, and public–private partnerships influence decision-making. Donor financing to water supply systems and its effects on water system decision-making for equitable distribution of water could also be an area for future exploration.

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