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Including water quality monitoring in rural water services: why safe water requires challenging the quantity versus quality dichotomy

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The need to increase drinking water quality monitoring in rural sub-Saharan Africa is widely recognised. Rural water service providers (RWSPs) may be positioned to include water quality monitoring in their activities; however, it is important that water safety activities do not compromise cooperation between the RWSP, bureaucracy, and communities. Using dilemma analysis, drawing on an institutional experiment engaging 76 stakeholders, we find that conceptualising water quality versus quantity as a dichotomy delays progress on safe water. This false dichotomy makes it more difficult to deliver water safety improvements due to contrasting assumptions about the importance of quality; risks associated with not being able to act; and unclear divisions of responsibility. Monitoring water quality can be a threat to stakeholders and stakeholder cooperation; however, this may be mitigated by including supported water safety planning in the technical and institutional design of rural water projects at their conception.

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INTRODUCTION

The global sustainable development agenda includes an ambition to monitor drinking water quality in rural areas. In some countries this need is also reflected in national legislation. In Kenya, for example, access to safe water has been a constitutional right since 2010 and the 2016 Water Act established that county governments are responsible for rural water provision that meets national regulatory standards[1]. Monitoring is required for operational and regulatory purposes to sustain safe supply and assess the reality of service provision against expectations established by standards. Consequently, water sector regulators and donors are considering options to enable monitoring of the small, numerous rural schemes that are currently not visible to them[2,3].

Baseline data for the Sustainable Development Goals (SDGs) estimated that a quarter of the global population lacks safe drinking water[4], and highlighted a stark divide between urban and rural access to 'improved' and 'safe' sources[5]. In Sub-Saharan Africa (SSA), as of 2017, about half of urban dwellers were using 'safe' water, compared to only 19% of rural dwellers[6]. Additionally, water quality monitoring in rural SSA is often minimal or absent[7,8]. Thus, the inequality is twofold: rural areas have less access both to safe water and to water quality information. To realise universal access to safe water, novel arrangements are needed to build institutional capacity and resources for rural water quality monitoring.

One potential avenue for increasing monitoring in rural areas is through the activities of rural water service providers (RWSPs): private companies or social enterprises that provide either maintenance or full water supply services in rural areas. RWSPs are founded on the idea that networking small supplies together can provide the economies of scale that are necessary for affordable, sustainable water supply. Here we refer to them as market-based, but most RWSPs are not fully independent market institutions because they rely on the private sector, donors, and, at times, the government to address the financing gap that results from consumers' low ability to pay for services. Relationships with government and communities are crucial for RWSPs to maintain their ability to operate and ensure demand for services[9].

Cooperation and risk-sharing between market entities (such as RWSPs), the communities they serve, and the bureaucracy that actively or passively allows them to operate is essential[9,10]. It is now increasingly recognised that the future of the rural water sector lies in pluralist institutional arrangements that account for the perspectives of multiple stakeholder groups and build compromise solutions that cater, at least in part, to the strengths and needs of them all[11,12]. Water quality monitoring addresses one of numerous aspects of water service provision and in order to productively contribute to improved management of water supply risks generally, it must be conducted in a way that does not threaten institutional cooperation.

This means that in assessing whether to include water quality monitoring in rural water service provision, and how to include it, RWSPs must consider their own interests and those of the bureaucratic and community stakeholders that they engage with. These interests are interrelated and subject to contradiction and instability, particularly because the relative absence of existing rural water quality monitoring programmes leaves procedures and responsibilities poorly defined. Thus, the conception and design of water quality monitoring programmes presents as an aggregate of dilemmas—a situation characterised by systematic complexity in which a course of action is difficult to resolve. For water quality monitoring to effectively lead to sustained improvements in drinking water safety, it is necessary to understand and mitigate conflicts of interests within and between RWSPs, bureaucratic divisions, and communities. In this study, we analyse stakeholder views to identify and characterise the multiple dilemmas faced in including water quality monitoring in rural water services.

Stakeholder views on whether and how water quality monitoring should be done by RWSPs were captured through

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interviews, informal meetings, questionnaires, surveys, and document review. A layered approach centred the study on a water quality monitoring programme that was designed and executed in collaboration with a RWSP in Kenya. Perspectives were sought from county and local government ($n = 4$) as well as community lay water managers (LWMs) with whom the RWSP had a contractual relationship ($n = 58$). Here LWMs are members of community water management committees, private owners, and administrators in schools and health facilities who oversee the daily operations of water supplies that serve the public. We then built upon this central focus by including perspectives from national-level government ($n = 2$) and regulators ($n = 2$), formal water service providers (FWSPs) in Kenya ($n = 6$), and additional RWSPs operating across five countries in SSA ($n = 5$).

We used dilemma analysis to describe the views of service providers, bureaucratic representatives, and LWMs, and to assess them 'as parallel rationalities, without the hierarchical valuation which conventionally discriminates between them' (p. 167)[13]. The dilemma analysis methodology directs focus not to the opinions of stakeholders, but rather to the issues about which their various opinions are held. Applied to the case of rural water quality monitoring, dilemma analysis allows contrary perspectives to be expressed within and between individuals and organisations. Importantly, this approach ascribes equal weight to bureaucratic and community opinions, which are both important for a RWSP's ability to operate. The dilemmas are grouped into topics, and each topic is assigned as ambiguity, judgement, or problem to indicate the severity of its component dilemmas as perceived by the stakeholders themselves. The interrelatedness of these topic groups is then explored (see Methods section for details).

The results of the dilemma analysis point to strategies that can better align rural water service provision with the global agenda for universal access to safe drinking water. In the following sections, we summarise the results, highlighting important repercussions of conceptualising provision of water quantity as separate from provision of water quality. Considering these findings, we discuss the importance of contextualising monitoring information, the need for external support to address water safety, and the value of incorporating institutional and technical capacity for ensuring water safety into projects at their onset.

RESULTS

The analysis resulted in 111 described dilemmas that revolve around minimising perceived risks and adhering to moral principles. The dilemmas are reflections of conflicting viewpoints, within individuals or within each institutional group (market, bureaucracy, or community). There were no instances of an institutional group expressing unilateral agreement with one side of a dilemma in opposition to another group; however, in many cases dilemmas are formed around the assumptions made by individuals in one group about the impact of choices on and by another group. Conflicting viewpoints persists within and between stakeholders because the dilemmas consist of comparisons between different types of risk and present choices that require the favouring of one moral principle over another. How does one compare the threat of disease to the threat of reputational damage or the threat of maladaptive behaviour change? Or weigh the right to information against the moral imperative to avoid causing undue distress?

The dilemmas are grouped by their relevance to 19 topics, as described in Table 1. The topics are strongly interrelated and Fig. 1 depicts 69 of the most substantive links between them. The topics are disaggregated by stakeholder group: bureaucracy (blue), community (magenta), and market (green). The darkness of the links between topics indicates their influence on generating, using, and sharing monitoring information: the darkest links are deterrents, neutral links are medium grey, and enabling links are light grey.

Only nine links are monitoring enablers. Eight of these relate to communication mode (topic S5 in Table 1), and more specifically the advantages of a full-programme educative approach to sharing water quality monitoring information with LWMs and users. The ninth enabler relates to RWSPs, whose enthusiasm for including monitoring in their service package (G3) is increased by anticipating attracting investment through sharing monitoring results with sector partners (S4).

In contrast, just over half (36) of the links depicted in Fig. 1 represent barriers to effective monitoring. Twenty-three of these barrier links are within-group. Within the community group, for example, there is a barrier between responsibility to use (E3) and allowing monitoring (G2). Generally, LWMs were wary of allowing monitoring when responsibility for responding to results was unclear. When LWMs perceived that they were responsible for the quality of the water, however, they were less wary of monitoring but placed more emphasis on confidentiality of results (S1).

In addition to the within-group barrier links, there were 13 barrier links between stakeholder groups. Two of these were related to difficulty on the part of RWSPs in judging whether and how to share information with users (S1) and LWMs (S2) given government concerns around confidentiality. A third barrier arose due to differential preferences from RWSPs and communities regarding meaningful versus feasible modes of communicating results (S5). The remaining ten barriers were related to the problem topics of access priority (G1), responsibility to use (E3), empowerment (R5), and entitlement to results (S6). In general, access priority (G1) is one of the most influential topics. It is applicable for all three stakeholder groups, being comprised of 14 dilemmas in total, and is a component of 22 links between topics (as emphasised by thicker lines in Fig. 2). It is further unpacked in the following sections.

Contradictory assumptions obscure disempowerment

From the bureaucratic perspective, national policy mandates that county governments supply safe drinking water. But these national directives are non-binding and open to interpretation. Budgets are allocated at county level, where they are heavily influenced by election politics. Water supply is an important campaign issue, but quality only becomes politically important when people are focused on problems with it. There is an important link between access priority (G1) and allowing sharing with the public (S1 and S2) that is explained by the prevalence of two contradictory assumptions: first that users do not care about water quality and second that revealing water quality problems to users will distress them and cause political backlash.

This theme, that users do not care about water quality although it is important to them when they believe it to be a threat, persists in the market perspective as well.

> *Across the board, rural water users do not really care about water quality unless you're in a place that has been affected by a cholera outbreak in recent memory… Whether it's the government side or users, there's little demand for water quality.—RWSP 5*

While the community LWMs did express that water safety is a lower priority than having water at all, their access priority dilemmas are centrally related to a lack of empowerment (R5). Here we can express the dilemma as

Table 1. Summary of dilemma groupings by stage and topic.

Stage	ID	Topic	Topic explanation	No. of dilemmas	Applicability[a]	Type[b]
Generate info	G1	Access priority	The relative importance of quantity versus quality, with water safety perceived as distinct from concerns of access to basic water services.	14	CMB	P
	G2	Allow monitoring	Approve of, versus object to, monitoring being done by RWSPs.	7	CB	J
	G3	Include monitoring	Include or exclude monitoring from regular activities, with perceptions of responsibility to monitor of central importance	12	MB	J
	G4	Monitoring design	Sampling design choices such as what parameters and locations to include and frequency of sampling	8	MB	J
	G5	Lab certification	Use of government certified (usually centralised) labs versus use of field kits and minimalistic field labs	5	MB	J
Share info	S1	Share to users	Rationale for and against sharing water quality monitoring information with users (perspectives of users are not included)	11	CMB	J
	S2	Share to LWMs	Rationale for and against sharing water quality monitoring information with LWMs	2	MB	J
	S3	Share to bureaucracy	Rationale for and against sharing water quality monitoring information with bureaucracy	4	CM	J
	S4	Share to sector partners	Rationale for and against sharing water quality monitoring information with NGOs and donors (perspectives of partners not included)	4	CMB	J
	S5	Communication mode	A full-programme educative approach to sharing with LWMs and/or users versus a paternalistic approach of partial sharing	2	CM	A
	S6	Entitlement to results	Rationale for and against the assertion that LWMs are entitled to the results of water quality monitoring	1	C	P
Engage with info	E1	Utility	Rationale for dismissing new information versus engaging with and consequently changing beliefs, assumptions, or workplans on the basis of it	5	CB	J
	E2	Power versus bliss	Rationale for whether or not knowledge is empowering (when and how), articulated by many as 'knowledge is power' and conversely that without ability to respond to threats, being informed of them causes unwarranted distress so ignorance is preferable (or 'bliss' as in the English idiom)	1	C	A
	E3	Responsibility to use	Taking versus attributing responsibility for responding to the results of water quality monitoring	13	CMB	P
Respond to info	R1	Urgency	Rationale for and against immediate, localised response versus developing strategic large-scale solutions over the long-term, as articulated by service providers on the basis of meeting expectations of community versus government stakeholders	2	M	A
	R2	Source choice	Weighing options for sourcing water	6	CMB	J
	R3	Protection choice	Weighing options for protecting source water	3	C	J
	R4	Treatment choice	Weighing options for treating water at the source, point of collection, and or in the household	9	CM	J
	R5	Empowerment	Wanting to act versus not having the financial resources and knowledge with which to act (as articulated by LWMs) OR debate about the relative importance of financial versus knowledge barriers to action (as articulated by the bureaucracy)	2	CB	P

[a]Applicability: C = Community, M = Market, B = Bureaucratic.
[b]Type: A = Ambiguity, J = Judgement, P = Problem.

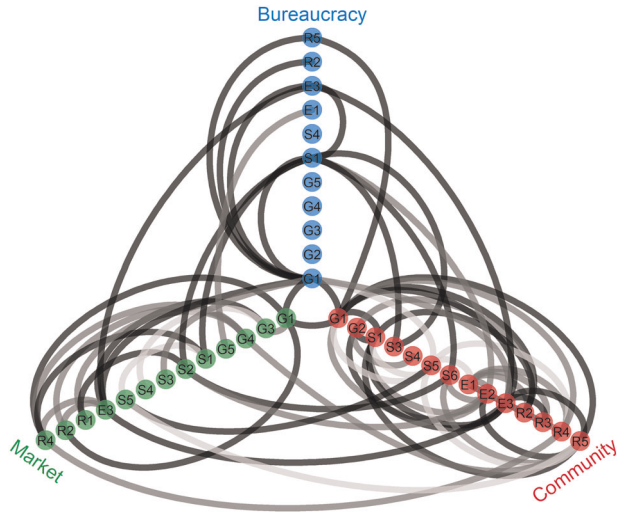

Fig. 1 Axial hive network visualisation of links between dilemma topics. Axes represent stakeholder groups with blue=bureaucracy, magenta=community and green=market. Nodes refer to the topics described in Table 1 and are organised by stage (generate, share, engage, respond). Black line indicates a barrier, discouraging monitoring. Medium grey indicates neutral influence. Light grey indicates enabling monitoring.

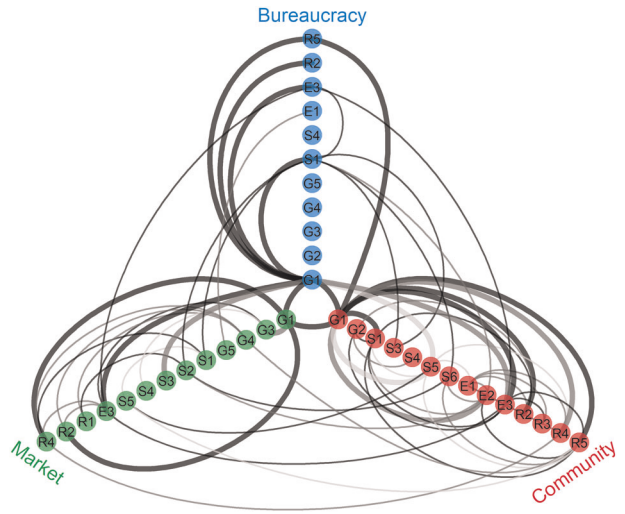

Fig. 2 Axial hive network emphasising 'access priority' topic links. Axial hive network visualisation of links between dilemma topics with links to 'access priority' (topic G1) emphasised by thicker lines.

- On the one hand, LWMs would like to adopt the multibarrier approach with protection, cleaning, and disinfection measures. And they are amenable to separating and treating a smaller volume of water specifically for drinking.
- On the other hand, they

(a) do not have funds for necessary infrastructure, equipment and/or consumables.
(b) do not know how to seek or raise funds.
(c) are not experts and do not feel confident in whether, or how, to carryout measures.

The above dilemma conceptualises empowerment in terms of both resources and knowledge. The importance of knowledge is further elaborated in the power versus bliss topic (E2), i.e. whether knowledge is empowering or ignorance is bliss, where many LWMs articulated the importance of knowledge for enabling consideration of previously unrecognised issues.

> *people are dying because of lack of knowledge. You know, they may prefer that one because it is fresh, but it's risky. But unless somebody comes in and does some testing, we just assume [it is good to use] – our grandfathers used it. So, we continue with that problem. And you might find, a community like this one, having a chronic issue because of lacking people to bring them to light.—Committee 6*

> *if we shall be able to know, we can ask [the government]: how far have you reached in solving this problem? But when we don't know whether there is a problem then we cannot ask them because we think everything is okay. —Facility 9*

Water quality monitoring as a threat to supply

Across all institutional groups, the access dilemmas include fears that water quality monitoring threatens basic supply by splitting resources; by causing controversy that destabilises management and compromises ability to operate; by revealing that a supply must be shut-down due to geogenic chemistry problems; or by necessitating treatment approaches that require supply disruption. RWSPs expressed this dilemma as

- On the one hand, water quality testing identifies quality problems and enables corrective actions to be taken.
- On the other hand, corrective action can threaten supply since contamination can be difficult to treat and closing a source without providing a better alternative is not in the best interest of the users.

For LWMs, concerns about monitoring causing controversy that would destabilise management and prevent ongoing functionality of water supplies were associated with perceived need for confidentiality of monitoring results (S1).

> *we should not [share to users] because that one will jeopardize, with politics, everything. There will be politics, and then the project will not help the community at all. If they are going to bring politics, it is going to die, the project may die out.—Facility 16*

Unclear division of responsibility

The access priority (G1) dilemmas of each institutional group are interrelated and mutually reinforcing, with each justifying their

own lack of priority for water safety at least partly on the basis of the others not prioritising it. Due to the associated politics, disempowerment, and perceived threats to functionality of supplies, the access priority dilemmas result in abnegation of responsibility for water safety in all three institutional groups. If an RWSP introduces monitoring in this context, in the absence of operationalised responsibility for water safety, they draw attention to the question of who is expected to respond to identified water quality threats. As with the access priority dilemmas, the dilemmas around responsibility to use (E3) are interrelated. But in this case, rather than being mutually reinforcing, they create a debate—about legislated mandates versus perceived moral and practical responsibilities—that compromises institutional cooperation.

The bureaucracy may have a legislated mandate, but the lack of operationalised responsibility for water safety in the rural water sector has left a void. There is a popular notion that all stakeholders have a role to play in securing safe water, but roles are poorly defined in practice. As a result, lack of action on the part of one institutional group is frequently justified by shifting responsibility to another.

> *The moment these projects are handed over to the community, we are through with them. But now I think they are training the communities on how to handle these things. —County representative 3*

By introducing water quality monitoring into the current void, RWSPs (whose main role is maintaining functionality of existing supplies) may find themselves cast as instigators—with responsibility to respond to monitoring results largely defaulted to them by consequent expectations from bureaucracy and communities.

> *I think it is maybe our way of thinking, us as Kenyans and Africans, that if you are looking out for any problem, you are also having a package of the solution—Facility lay water manager 21*

DISCUSSION

Rural water service provision typically prioritises quantity over quality, which is often assumed to be adequate where groundwater is used. This practice maintains the separation of water safety from other aspects of rural water service provision, thereby establishing a false dichotomy—one that is reinforced by contradictory assumptions about whether water quality matters to the public. These assumptions obscure issues of community access to resources and knowledge. The empowerment dilemma expressed by LWMs in terms of intent to manage versus ability to pay, action knowledge[14], and self-efficacy[15,16] is reflected in the literature on the sustainability of (a) community self-financing of recurrent operations and maintenance costs[17,18] and (b) water safety behaviour at the household-level[19–21]. Researchers have called for further exploration into the roles of ability to pay and self-efficacy for determining sustainable service delivery[18] and sustaining safe water behaviour[22]. Here we demonstrate the significance of these empowerment dimensions for water safety management at the community scale and emphasise that lack of empowerment does not equate to apathy.

Moving beyond the question of whether water quality matters, and to whom, the dilemma analysis also revealed that water quality monitoring is deterred by fears that it will threaten functionality. Thereby, further reinforcing the quantity versus quality dichotomy. Fears relate to a lack of contextualisation and a reactive mode of operating in which solutions to quality concerns involve supply disruption or closure. But fears are also related to disempowerment, and the self-preserving requirement to avoid attracting criticism by revealing problems that one cannot resolve. Responsibility is a key point of contention.

Indeed, perhaps the biggest deterrent of monitoring is that it draws attention to the question of who is responsible for using the results (this question is additionally complex because perceived responsibility varies with contaminant type). Introducing monitoring can reveal problems that nobody realised were there, leading multiple stakeholders in interviews to liken it to opening Pandora's box. As a result, RWSPs that take on water quality monitoring encounter dilemmas about their organisational identity and purpose and may find themselves facing opposing demands from bureaucracy and community regarding how the results of monitoring are shared and used. This could be problematic given the importance of institutional cooperation for advancing service delivery in rural areas.

Yet, the assumptions, fears, and abnegation of responsibility that deter rural water quality monitoring may be mitigable. There is a need:

- to contextualise monitoring results so that quantity and quality are jointly considered.
- for external support to empower LWMs to engage with water safety and to enable bureaucratic divisions and service providers to act on responsibilities.
- to approach the technical and institutional design of water supply systems such that quality is considered early—thus increasing ability to respond to problems.

These needs are consistent with an established risk-based approach: water safety planning[23]. As of 2017, 93 countries had implemented water safety planning at varying scales, and although uptake has been relatively low in Sub-Saharan Africa, at least 10 countries are engaged in efforts to scale-up the use of the approach in both urban and rural areas[24]. This includes Kenya, where the national water services regulator has published guidance promoting the approach[25]. In the following sections, we briefly discuss how the barriers identified by the dilemma analysis may be addressed through a water safety planning approach. In so doing, we also speak to the main challenges of implementing water safety planning in rural areas.

Contextualising monitoring results

The WHO have recommended water safety planning since 2004; they continue to do so[23] and practical guidance is readily available[26,27], including specific adaptations for small community supplies[28–32]. Rather than relying on a purely reactive management approach, which reinforces the quality versus quantity dichotomy, water safety planning seeks to identify and address risks holistically and pre-emptively. Within the water safety planning model, quality, quantity, proximity, reliability, and acceptability of supply are to be considered concurrently to minimise use of supplementary water from unimproved sources and unhygienic storage. When implemented as intended, such an approach should alleviate functionality fears by encouraging consideration of monitoring results in terms of overall health burden.

By design, water safety planning should improve contextualisation of water quality information and, therefore, has potential to mitigate some of the barriers that were highlighted by the dilemma analysis. But the key challenge here is implementing the

approach as intended. Reactive management and associated 'obstruction of water delivery' has been described even for cases where water safety planning is actively being attempted[33] (p. 5). As discussed in the following sections, implementing water safety planning as intended is likely to require external support and early inclusion.

External support is needed

The dilemma analysis found that lack of empowerment creates barriers to improving water safety through monitoring. This is also reflected in the literature on water safety planning, which frequently highlights inadequate financing[34–37] and capacity[34,35,38–40] as substantial barriers to successful implementation. In rural areas in particular, inadequate financing and capacity have meant that water safety planning efforts focus on the early stages of the approach (assembling a team, describing the water supply and identifying hazards, developing and implementing a plan for improvement) but neglect the latter stages of monitoring, verification, and iterative learning[33,39], which are crucial to the effectiveness and sustainability of the approach[29,37]. Financial and capacity-building support is needed.

External support for rural water services is not new, a review of studies assessing external support provision since the 1970s describes support in many forms, provided by NGOs, governments, community associations, or businesses[41]. Half of the studies in the review focussed on SSA. Ironically, the most reported challenge for external support programmes was that providers themselves lacked sufficient resources to adequately support communities. The RWSP model is a hybrid in that it leverages resources from the private sector, donors, and government, as well as consumers. RWSPs, with their ability to capitalise on economies of scale and attract centralised funding and well-trained staff, are potentially positioned to channel and appropriately localise support for water safety planning.

Nevertheless, sharing results with LWMs and users in a way that builds understanding and is consistent with a holistic view of safety requires a full-programme educative approach to communication. The dilemma analysis highlighted that such an approach is important for enabling stakeholder cooperation around monitoring. Additionally, this comprehensive approach is consistent with official guidance and research studies that have recommended that rural water safety planning efforts include hazards occurring on consumers' premises[26,37,42], since addressing such hazards requires long-term effort towards sustained behaviour change. From the RWSP perspective, however, while the benefits are recognised, there are persistent doubts about scalability of a comprehensive approach. Further work investigating the financial and logistical feasibility of incorporating such an approach in the RWSP model would be useful.

Early adoption of water safety planning

With external support in place, monitoring and the latter stages of water safety planning become more feasible. The dilemma analysis found, however, that barriers to monitoring go beyond issues of finance and capacity. While external support should empower more action on water safety, there will always be trade-offs on how resources are used, and the convention of dichotomising quantity and quality will continue to hamper water safety efforts. The dichotomy sustains the view that taking responsibility for water safety is an excessive burden. As reflected in the literature, this view of monitoring—and water safety planning more broadly—as burdensome is a key difficulty for securing buy-in to the approach[35,43,44]. Though we have focussed in this study on rural context, the quantity versus quality dichotomy has broader relevance. For example, a study of water safety planning in urban utilities in India, Uganda, and Jamaica described a 'deliver first, safety later' mind-set among customers and implementers, which the researchers deemed a 'significant limiting influence on [water safety plan] implementation' (p. 902)[45].

The water safety planning approach aims to supersede the vague notion of 'everyone having a role to play' in ensuring water safety, by requiring that specific, actionable responsibilities be allocated. But fragmented institutional structures make meaningful stakeholder engagement difficult[46] and technical path dependencies limit viable response options. When a water safety planning approach is adopted early in the life of a water supply project, it can contribute to institutional design (including allocation of responsibilities) and technical design (maximising the choice of viable source selection, protection, and treatment response options). Thus, early water safety planning may clarify and operationalise responsibilities for water safety. In combination with sufficient external support, it may mitigate the barriers that otherwise arise from uncertain responsibilities and reticence towards raising awareness of quality concerns without an ability to respond to them. Early adoption is also beneficial when considered in light of 'community readiness'[44], because safety considerations are built into the design of a new system rather than being retrofitted to an existing system, when the acceptability of change and scope for community input are much reduced.

When quality issues are not adequately contextualised and strategies are not in place to address them, water quality monitoring can threaten cooperation between bureaucratic, market, and community institutional groups. In exploring the potential of RWSPs in SSA to contribute to the SDG 6.1 effort, we highlight the importance of building a technical and institutional structure around water quality monitoring so that it adds legitimacy to each institutional group rather than threatening them. Such a structure is consistent with the intentions of the water safety planning approach, which may be effective given external support and especially if adopted early. Those who fund rural water service provision should consider that a quantity first, quality later approach makes securing water safety additionally difficult because technical and institutional path dependencies limit response options and discourage stakeholder cooperation around monitoring. Instead, systems should be designed with preventative risk management in mind from the outset.

METHODS

This study centred on a RWSP in Kenya and their key bureaucratic and community relationships. 'Community' is used here as a cluster term for different types of management arrangements including fully community-managed, privately managed, and managed by schools and health facilities. Perspectives were also sought from national-level bureaucratic stakeholders (these being the regulators and Ministries of Water and Health), FWSPs (which supply mostly urban areas and are subject to regulation), and other RWSPs (which operate across five countries in SSA). As shown in Fig. 3, the three primary stakeholder groupings in the study are market (RWSPs and FWSPs), bureaucracy (Ministries of Water and Health and regulators at national, county, and local level), and community (LWMs, not general users). This design was chosen to align with existing work on institutional pluralism in the rural water sector[9]. Although the terms market, bureaucracy, and community are used to refer to the different viewpoints, it is acknowledged that hybrid representations exist on the ground.

A water quality monitoring programme was designed in collaboration with the core RWSP, which had previously not undertaken any such work. Starting in December 2018, monthly testing was conducted for a variety of microbial and chemical parameters at 88 sites of varying types in their service area. A range of both microbial and geogenic water quality concerns were identified in this process. The sites are clustered around a set of 56 locales and we included the most improved site, in terms of infrastructure, in each locale and then where possible added other sources that we were told were important for the communities. Approximately two-thirds of the communities that were engaged in the sampling programme were registered with the RWSP for maintenance services. The

other third were chosen to include LWM perspectives from communities that had not decided to engage with the RWSP. The proportion of registered versus non-registered was constrained by sign-up rates in the study area.

The water quality monitoring programme formed a foundation for the study by enabling engagement with stakeholders to be centred on actual rather than hypothetical activity. A series of methods were used to engage stakeholders both before and during the monitoring to elicit their views on the sampling activity itself and the resulting information (Table 2). Before beginning the work, a research permit and ethical approval were obtained from the Kenyan National Council of Science and Technology and the University of Oxford's Central University Research Ethics Committee, respectively. All participation was informed and uncompensated. Engagement with participants was contingent upon consent from participants after they were informed of the study process and objective verbally (and in writing when participants were literate). Personal identifiers were stored only for the duration of the study and in a secured platform.

For the bureaucratic group, multiple interviews were conducted in each division where possible (with the number of individuals interviewed ranging from 1 to 4). The total number of individuals interviewed over the 8 bureaucratic divisions was 17. For the LWMs, a primary contact was selected to represent each committee or facility. Thus, the resulting analysis does not consider dynamics within community management committees or facility administrative teams. Repeated attempts were made in July and August to interview all 56 primary contacts who were engaged in the monitoring programme, but 4 school and 13 committee LWMs were not available during the interview period and 1 private LWM declined to be interviewed.

Most of the interviews were conducted in English, although 11 of the LWM interviews were conducted in Kiswahili or the local language with the help of two translators. The translators were local to the area and had experience working in water services. They worked together to agree on translations of both questions and responses before, during, and after the interviews. Most of the interviews were audio recorded and transcribed, but hand-written notes were used in two instances when the interviewee was not comfortable being recorded (one bureaucratic representative and one school LWM).

All of the methods were used to understand stakeholder views on the utility, challenges, and possibilities of rural water quality monitoring. Respondents were not asked to identity contradictions or dilemmas outright; these were uncovered during the subsequent analysis.

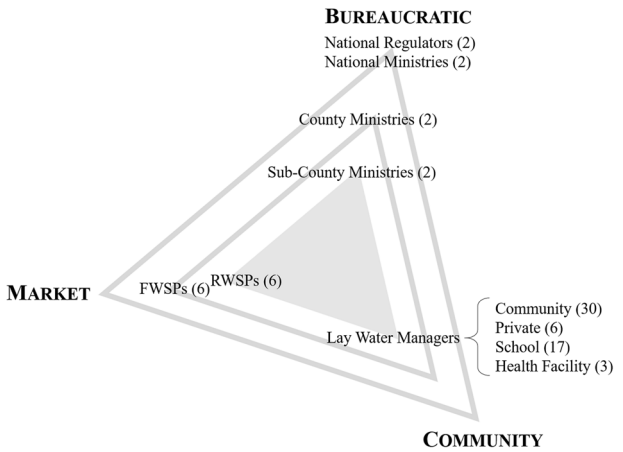

Fig. 3 Multi-level stakeholder engagement design. Stakeholder grouping nested from local to national level (numbers in brackets indicate the number of organisations or bureaucratic divisions included in each category).

Dilemma analysis

Dilemma analysis was first described in 1982 (ref. [13]) and has been used primarily within educational action research[47]. Broadly, its purpose is 'to find and juxtapose inconsistencies and contradictions that inhabit professional practice and decision-making' (p. 139)[48]. Dilemma analysis aligns with other post-structuralist techniques, such as polyvocal analysis, in that it recognises the coexistence of multiple truths that are 'always partial, local, and historical' (p. 202)[49]. This version of dilemma analysis is not to be confused with social dilemma analysis, which focuses on conflicts between individual and collective interests, nor with confrontation analysis, a game theory method that is also sometimes referred to as dilemma analysis.

In order to avoid influencing the expression of dilemmas by appearing partisan, the field researcher identified herself to stakeholders as an independent researcher rather than an affiliate of the core RWSP. Nevertheless, the bureaucratic and community stakeholders would have associated her with the RWSP to some degree because the monitoring programme that they were carrying out was discussed and she was evidently well-informed about the specifics of what was monitored and reported.

The dilemma analysis produced three successive outputs. First, data were gathered into NVivo and subjected to versus coding[48], the objective of which is to draw out contradictions, including both those that indicate polar opposition and inconsistency[50]. During an initial round of coding, the contradictions were grouped by their relevance to generation of, sharing of, engagement with, and mode of response to water quality information. These groupings broadly mirror the structure of the interviews, which elicited participants' views on the various stages of monitoring in chronological order. The coding framework was refined during a second round of coding that introduced sub-topics under each of the aforementioned stages. Thus, the first output of the dilemma analysis is an organised compilation of contradictions that capture inconsistencies in the views expressed by and between stakeholders.

The compilation of contradictions does not exhaustively include all contradictions expressed by FWSP and bureaucratic representatives; priority was given to contradictions that have relevance in comparison with the RWSP situation. For example, contradictions concerning the lack of engagement between county Ministries of Water and FWSPs around water quality monitoring were not included. Contradictions relating to overlapping mandates and information sharing between bureaucratic

Table 2. Data collection methods.

Method	Activities
Semi-structured Interviews	LWMs ($n = 38$): July to August|RWSPs ($n = 6$): September|National bureaucracy ($n = 4$): April|County and local bureaucracy ($n = 4$): July to August
Questionnaires	LWMs ($n = 56$): one in November and one in January
Surveys	LWMs ($n = 56$[a]): monthly from December to November
Meetings	County and local bureaucracy ($n = 3$): November and February
Document review	County level: County Integrated Development Plans|National Drought Management Authority County Long and Short Rains Reports|County WASH Forum Meeting Minutes National-level: (Kenyan) Water Act 2002, 2016|The (Kenyan) Water Resources Regulations 2019|The (Kenyan) Water Services Regulations 2019|WASREB Guidelines on Drinking Water Quality and Effluent Monitoring|Ministry of Water Strategic Plan 2018-2022|Ministry of Water National Water Services Strategy 2007–2015

[a]Not all primary contacts were available to answer the survey questions in-person each month, so phone calls were used when necessary.

divisions were also left out. As were contradictions around (dis) empowerment of actors on the lower rungs of the bureaucratic hierarchy.

The second output is a perspective document, which condenses the listed contradictions into dilemmas, organised by stakeholder group. Here dilemma is defined in the narrow sense as a choice between two alternatives, neither being unambiguously preferable. The perspective document was not shared back with stakeholders due to sensitivity of some of the dilemmas (taking care to avoid breach of confidentiality or negatively impacting on existing institutional cooperation) and linguistic complexity (as a barrier to meaningful engagement).

Dilemmas are formulated in an inclusive form that is more elaborate than any one individual would have expressed, but which any one individual of the relevant group would assent to. They are expressed by a 'on the one hand'/'on the other hand' construction and are categorised at multiple levels: first by stakeholder group (market, bureaucracy, community), then by monitoring stage (generate, share, engage, respond), and finally by topic. As shown in Table 1, topics are categorised as ambiguities, judgements, and problems to indicate the perceived severity and importance of the component dilemmas. Ambiguity dilemmas relate to aspects of a situation that are viewed as unavoidable, they describe 'background awareness of inevitable and deep-seated complexities' (p. 169)[13], but are tolerated because they do not link directly to a course of action. Judgement dilemmas relate to choosing a course of action when the decision is deemed complex but not inherently negative. Judgement dilemmas can be satisfactorily resolved with skilful handling. Problem dilemmas also relate to choosing a course of action, but in this case the necessity of deciding is itself negative. Problem dilemmas represent strong, intractable conflicts of interest within and between stakeholders. The final stage of the analysis was to record links between the topics, these were either directly expressed by stakeholders or were inferred during the analysis.

Visualising links between dilemma topic groups

In order to explore the interrelatedness of the dilemmas, the final stage of the analysis was to compile a list of associations between dilemmas. These associations were both between and within stakeholder groups (market, bureaucracy, community). As mentioned at the beginning of the results section, in many cases dilemmas are formed around the assumptions made by individuals in one group about the impact of choices on and by another group. Furthermore, as the analysis is organised by different stages of the monitoring process (generating, sharing, engaging, responding), within a stakeholder group, dilemmas of one stage related to dilemmas in other stages.

The list was developed through an iterative process of recording associations between dilemmas that were either directly expressed by stakeholders or were inferred during the dilemma analysis and afterwards upon review of the perspective document. The associations were then assessed at topic level disaggregated by stakeholder group. Where the associations between the dilemmas of two topic groups were such that generating, using, or sharing monitoring information is discouraged, on balance, by the prevalence of conflicting standpoints the link between the two topic groups was classified as a barrier. Where dilemmas were overall aligned to facilitate water safety improvement, the link was classified as an enabler. A neutral classification was given to links when the associations between dilemmas have value for informing design of cooperative monitoring programmes but were not sufficiently impactful to be considered sources of substantial conflict or facilitation.

An axial hive network visualisation was used to depict the links between topics disaggregated by stakeholder group (Fig. 1). The purpose of the visualisation is to demonstrate the complexity of links between the dilemma topics and to emphasise that there are numerous barriers to effective water quality monitoring because of divergent stakeholder views. It was created using R version 3.6.1 (2019-07-05) with the package 'ggraph'[51].

DATA AVAILABILITY

A partial example from the perspective document is provided in Supplementary Information (Table S1) to help illustrate the dilemma analysis method. The full document is not provided for confidentiality reasons, but additional excerpts from the document can be made available upon request to the corresponding author.

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REFERENCES

1. Government of Kenya. *The Water Act: No. 43 of 2016*. **164** (Government of Kenya, 2016).
2. Gerlach, E. *Regulating Rural Water Supply Services: A Comparative Review of Existing and Emerging Approaches with a Focus on GIZ Partner Countries* (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2019).
3. WASREB. *Guideline For Provision of Water and Sanitation Services in Rural and Underserved Areas in Kenya* (2019).
4. JMP. *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. (2017).
5. JMP. *Progress on household drinking water, sanitation and hygiene 2000–2017. Special focus on inequalities* (2019).
6. JMP. *UNICEF WHO Joint Monitoring Programme: Data*. https://washdata.org/data. Accessed 6 October 2019 (2019).
7. Peletz, R., Kumpel, E., Bonham, M., Rahman, Z. & Khush, R. To what extent is drinking water tested in sub-saharan Africa? A comparative analysis of regulated water quality monitoring. *Int. J. Environ. Res. Public Health* **13**, 1–14 (2016).
8. Marks, S. J. & Schwab, K. J. In *Routlledge Handbook of Water and Health* (eds. Bartram, J. et al.) 336–344 (Routledge, 2015).
9. Koehler, J., Rayner, S., Katuva, J., Thomson, P. & Hope, R. A cultural theory of drinking water risks, values and institutional change. *Glob. Environ. Chang.* **50**, 268–277 (2018).
10. Thompson, J. et al. *Drawers of Water II. 30 Years of Change in Domestic Water Use and Environmental Health in East Africa* (International Institute for Environment and Development, 2001).
11. Lockwood, H. & Le Gouais, A. *Professionalising Community- Based Management for Rural Water Services*. Briefing note: Building blocks for sustainability series (IRC, The Hague, Netherlands, 2015).
12. Thompson, M. In *A Changing Environment for Human Security: Transformative Approaches to Research, Policy and* Action (eds. Sygna, L., O'brien, K. & Wolf, J.) (Routledge, 2013).
13. Winter, R. 'Dilemma Analysis': a contribution to methodology for action research. *Camb. J. Educ.* **12**, 161–174 (1982).
14. Frick, J., Kaiser, F. G. & Wilson, M. Environmental knowledge and conservation behavior: Exploring prevalence and structure in a representative sample. *Pers. Individ. Differ.* **37**, 1597–1613 (2004).
15. Bandura, A. *Self-efficacy: The Exercise of Control* (W.H. Freeman and Company 1997).
16. Bandura, A. Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* **84**, 191–215 (1977).
17. Harvey, P. A. Cost determination and sustainable financing for rural water services in sub-Saharan Africa. *Water Policy* **9**, 373–391 (2007).
18. Foster, T. & Hope, R. A multi-decadal and social-ecological systems analysis of community waterpoint payment behaviours in rural Kenya. *J. Rural Stud.* **47**, 85–96 (2016).
19. Mosler, H. J. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. *Int. J. Environ. Health Res.* **22**, 431–449 (2012).
20. Mosler, H. J., Blöchliger, O. R. & Inauen, J. Personal, social, and situational factors influencing the consumption of drinking water from arsenic-safe deep tubewells in Bangladesh. *J. Environ. Manag.* **91**, 1316–1323 (2010).
21. Figueroa, M. E. & Kincaid, D. L. Social, cultural and behavioral correlates of household water treatment and storage. *Center Publication HCI 2010-1: Health Communication Insights* (Johns Hopkins Bloomberg School of Public Health, Center for Communication Programs, 2010).
22. Dreibelbis, R. et al. The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC Public Health* **13**, 1–13 (2013).
23. WHO. *Guidelines for Drinking-Water Quality*. 4th edn incorporating the first addendum (WHO Press, 2017).
24. WHO & IWA. *Global Status Report on Water Safety Plans:* A review of proactive risk assessment and risk management practices to ensure the safety of drinking-water (2017).
25. WASREB. *Guideline on Water Safety Planning* (2019).
26. Bartram, J. et al. *Water Safety Plan Manual: Step-By-Step Risk Management for Drinking-Water Suppliers* (WHO Press, 2009).
27. WHO & IWA. *Think Big, Start Small, Scale Up: A Road Map To Support Country-Level Implementation of Water Safety Plans* (2010).
28. Greaves, F. & Simmons, C. *Water Safety Plans for Communities: Guidance for adoption of Water Safety Plans at Community Level* (2011).
29. WHO. Water Safety Planning for Small Community Water Supplies: Step-By-Step Risk Management Guidance for Drinking-Water Supplies in Small Communites (2012).

30. Rickert, B., Schmoll, O., Rinehold, A. & Barrenberg, E. *Water Safety Plan: A Field Guide to Improving Drinking-Water Safety in Small Communities* (World Health Organisation, Copenhagen, Denmark, 2014).
31. MWIE. *Climate Resilient Water Safety Plan Implementation: Guidelines for Community Managed Rural Drinking Water Supplies* (2015).
32. Mudaliar, M. M., Bergin, C. & MacLeod, K. *Drinking Water Safety Planning: A Practical Guide for Pacific Island Countries* (WHO/SOPAC Joint Contribution Report 193, SOPAC Secretariat, Suva, Fiji, 2008).
33. String, G. M., Singleton, R. I., Mirindi, P. N. & Lantagne, D. S. Operational research on rural, community-managed water safety Plans: case study results from implementations in India, DRC, Fiji, and Vanuatu. *Water Res.* **170**, 115288 (2020).
34. Kumpel, E. et al. Measuring the impacts of water safety plans in the Asia-Pacific region. *Int. J. Environ. Res. Public Health* **15**, 1–18 (2018).
35. Perrier, E., Kot, M., Castleden, H. & Gagnon, G. A. Drinking water safety plans: barriers and bridges for small systems in Alberta, Canada. *Water Policy* **16**, 1140–1154 (2014).
36. Chang, Z. K., Chong, M. L. & Bartram, J. Analysis of water safety plan costs from case studies in the Western Pacific region. *Water Sci. Technol. Water Supply* **13**, 1358–1366 (2013).
37. Rinehold, A., Corrales, L., Medlin, E. & Gelting, R. J. Water safety plan demonstration projects in latin america and the Caribbean: lessons from the field. *Water Sci. Technol. Water Supply* **11**, 297–308 (2011).
38. Ferrero, G. et al. Capacity building and training approaches for water safety plans: a comprehensive literature review. *Int. J. Hyg. Environ. Health* **222**, 615–627 (2019).
39. Kanyesigye, C., Marks, S. J., Nakanjako, J., Kansiime, F. & Ferrero, G. Status of water safety plan development and implementation in Uganda. *Int. J. Environ. Res. Public Health* **16**, 1–17 (2019).
40. Parker, A. & Summerill, C. Water safety plan implementation in East Africa: Motivations and barriers. *Waterlines* **32**, 113–124 (2013).
41. Miller, M. et al. External support programs to improve rural drinking water service sustainability: a systematic review. *Sci. Total Environ.* **670**, 717–731 (2019).
42. String, G. & Lantagne, D. A systematic review of outcomes and lessons learned from general, rural, and country-specific Water Safety Plan implementations. *Water Sci. Technol. Water Supply* **16**, 1580–1594 (2016).
43. Summerill, C., Smith, J., Webster, J. & Pollard, S. An international review of the challenges associated with securing 'buy-in' for water safety plans within providers of drinking water supplies. *J. Water Health* **8**, 387–398 (2010).
44. Kot, M., Castleden, H. & Gagnon, G. A. The human dimension of water safety plans: a critical review of literature and information gaps. *Environ. Rev.* **23**, 24–29 (2015).
45. Omar, Y. Y., Parker, A., Smith, J. A. & Pollard, S. J. T. Risk management for drinking water safety in low and middle income countries—cultural influences on water safety plan (WSP) implementation in urban water utilities. *Sci. Total Environ.* **576**, 895–906 (2017).
46. Ferrero, G., Bichai, F. & Rusca, M Experiential learning through role-playing: enhancing stakeholder collaboration in water safety plans. *Water (Switzerland)* **10**, 1–11 (2018).
47. Altrichter, H., Posch, P. & Somekh, B. *Teachers Investigate Their Work: An Introduction to the Methods of Action Research* (Routledge, 1993).
48. Saldana, J. *The Coding Manual for Qualitative Researchers*. (SAGE Publications Ltd, 2016).
49. Hatch, J. A. *Doing Qualitative Research in Education Settings* (State University of New York Press, 2002).
50. Gibson, W. J. & Brown, A. *Working with Qualitative Data* (SAGE Publications Ltd, 2009).
51. Pederson, T. L. *Package 'ggraph': An Implementation of Grammar of Graphics for Graphs and Networks*. CRAN (2019).

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AUTHOR CONTRIBUTIONS

S.N. designed the study with input from K.J.C. S.N. did the fieldwork and analysis, and led on paper writing with review and comments from K.J.C. and J.K throughout the process.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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